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External Shocks and Optimal Monetary Policy in Oil Exporting Small Open Economies

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Nomenclature

AMCON Asset Management Corporation of Nigeria

AR(1) Autoregressive Process of Order 1

ASI All-Share Index

BSVAR Bayesian Structural Vector Auto Regression

CBN Central Bnk of Nigeria

CES Constant Elasticity of Substitution

CIT Core Inflation Targeting

CITR CPI Inflation Targeting Regime/Rule

CPI Consumer Price Index

DINF Domestic Inflation

DIR Domestic Interest Rate

DITR Domestic Inflation Targeting Regime/Rule

DOG Domestic Output Growth

DSGE Dynamic Stochastic General Equilibrium

ERT Exchange Rate Targeting

ERTR Exchange Rate Targeting Regime/Rule

FDI Foreign Direct Investment

Fed US Federal Reserve System

FFR US Federal Funds Rate

FOCs First Order Conditions

FPI Foreign Portfolio Investments

Full Full Oil Subsidy (zero oil price pass-through)

GDS Global Demand Shock

GFC Global Financial Crisis

GOG Global Output Growth

HIT Headline Inflation Targeting

IFS International Financial Statistics

IMF International Monetary Fund

LOOP Law of one price

MENA Middle East and North Africa

NBS National Bureau of Statistics

NKDSGE New Keynesian Dynamic Stochastic General Equilibrium

OANK One-Agent New Keynesian

OIT Oil Inflation Targeting

OLS Ordinary Least Squares

OPG Oil Price Growth

OPS Oil Price Shock

OSR Optimized Simple Rules

Partial Partial Oil Subsidy (partial oil price pass-through)

QE Quantitative Easing

RBC Real Business Cycle

RGDP Real Gross Domestic Product

RHS Right Hand Side

ROW Rest of the World

SOE Small Open Economy

SVAR Structural Vector Auto Regressive

TOT Terms of Trade

UIP Uncovered Interest Rate Parity

UIP Uncovered Interest Rate

UNCTAD United Nations Conference on Trade and Development

US United States of America

USMPS US Monetary Policy Shock

VAR Vector Auto Regression

Zero Zero Oil Subsidy (full oil price pass-through)

Dedication

To God, Almighty for His Amazing Grace; and to my wife, Josephine for her unflinching love and support.

Acknowledgments

My profoundest gratitude goes to my supervisor, Professor Chris Martin, for believing in me and guiding me diligently through the years of this academic endeavour. I sincerely appreciate the Management of the Central Bank of Nigeria (CBN), for their commitment to employee development in the Bank. I am eternally grateful to my deceased parents, Mr. Emmanuel Oladunni and Mrs. Sarah Oladunni and other family members for shaping who i am becoming. Special thanks to my former guardians, Reverend & Mrs. S.A.O. Oyelade and Dr. and Mrs. I.O. Adesina who helped me in my desperate hours.

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Above all, I thank God for the grace to realise the dream of my youth!

Abstract

Using empirical and theoretical macroeconomic models, we explore external shocks, business cycle dynamics and optimal monetary policy in oil exporting small open economies. Paper one employs a sign restricted Bayesian structural vectorautoregression (BSVAR) to analyse how three external shocks, namely: global demand, oil price and the US monetary policy shocks impact on the Nigerian business cycle variables. Our main objective is to uncover the dominant drivers of the business cycle. The results show that the global demand shock and oil price shock are the principal foreign drivers of the Nigerian business cycle. The global demand shock contributes the most to the evolution of the domestic output growth and inflation while oil price shock exerts considerable pressure on the domestic interest rate and the terms of trade. Robustness exercise show that macroeconomic risk arising from the global demand shock is systematic, owing to its considerable impact on output and interest rate before and during the global financial crisis (GFC) of 2008/2009. However, the GFC increased inflation volatility. A policy package designed to maximise gains from positive global demand shocks, shield the domestic economy from effects of oil price oscillation and improve domestic economic resilience is advised.

Paper two builds a small open economy (SOE) New Keynesian dynamic stochastic general equilibrium (NKDSGE) model that feature domestic and foreign production sectors. There is a representative monopolistically competitive domestic firm which sets price according to Calvo (1983a) scheme and a representative perfectly competitive oil firm which produces crude oil exclusive for export and takes oil price as given. Oil imported from the SOE is combined with a foreign intermediate good in the rest of the world (ROW) to produce foreign final good which is in turn, imported by the SOE for consumption. The model is closed with Taylor (1993)-type monetary policy rule. Model calibration matches standard SOE and oil exporting emerging economy characteristics. Macroeconomic response to a simulated positive oil price shock indicates evidence of Dutch disease. The exchange rate appreciates while interest rate falls in response to the non-oil output decline, induced by the Dutch disease. Domestic inflation targeting policy rule is the most welfare-friendly in the class of optimized simple rules while the commitment policy dominates both discretion and optimized simple rules.

In paper three, we construct a small open economy New Keynesian DSGE model to capture important structural features of net oil exporting emerging economies. We establish a direct connection between crude and refined oil prices and highlight the seeming structural chasm between domestic oil and non-oil sectors in some net oil exporting countries. Results of a negative oil price shock simulated on the model show that, in a zero oil price pass-through environment, the choice of the particular inflation measure to target in the Taylor rule does not matter. This is because macroeconomic responses to the shock under all monetary policy specifications are similar. Such similarity tends to indicate that full oil subsidy which guarantees a zero oil price pass-through interferes with monetary policy transmission mechanism in the model economy. In addition, the negative oil price shock precipitates stagflation which manifests via the income and exchange rate channels. Under the assumption of perfect labour mobility, the shock triggers movement of workers from the oil sector to the non-oil sector, thereby boosting non-oil productivity and output. The central bank responds to inflationary and exchange rate pressures by raising the interest rate. Tight external borrowing condition adds an extra layer of external vulnerability to the negative oil price shock. Macroeconomic volatility is least palpable under the zero oil price pass-through scenario. The optimized simple rules policy exercise show that either core or oil inflation targeting maximizes welfare given zero oil price pass-through, while oil inflation targeting is welfare superior under partial or full oil price pass-through. Targeting core inflation seems the feasible optimal option for practical monetary policy purposes in net oil exporting small open economies.

Keywords: External Shocks, Sign Restrictions, Structural VAR, Oil Exporting Countries, NK DSGE Models, Optimal Monetary Policy

Chapter 1

Overview

There is a plethora of theoretical and empirical research on external shocks, business cycles and monetary policy. However, an overwhelming proportion is devoted to exploring issues focusing on industrialized economies; with relatively advanced technology, high productivity and sound macroeconomic fundamentals. Consequently, macroeconomic issues in developing and emerging economies have received limited attention in the literature. Considering the fact that these are small open economies, many of which rely on commodity export proceeds for foreign exchange earnings, government revenues and general growth support, it is imperative to understand the nature of foreign shocks driving their business cycles and the optimal monetary policy path to take in responding to the shocks. The literature is lean on issues relating to oil exporting emerging and developing economies, especially those employing recent advances in applied macroeconometric and general equilibrium macroeconomic modelling frameworks.

Consequently, we attempt to narrow this gap by studying external shocks and business cycle fluctuations with an empirical model; and by developing two theoretical macroeconomic models with structural characteristics of these economies, particularly in the oil exporting category. In chapter two, using the sign restricted Bayesian structural vector autoregression (BSVAR), we investigate the dynamic effects of external shocks on business cycle fluctuations in an oil exporting country - Nigeria. A small open economy framework is assumed to identify three external shocks impacting three foreign and four domestic variables. The restrictions imposed on the model are informed by theoretical intuitions from Mumtaz & Surico (2009), Kilian & Lewis (2011), Olayeni (2009a) and Allegret & Benkhodja (2015). Our sample is partitioned into two, with the full sample covering quarterly dataset over the period 1982Q1 - 2016Q1 and the second sample covering the period 1982Q2 - 2007Q4. The second sample excludes dataset from the period of the global financial crisis till 2016Q1 for a robustness exercise to check whether the global financial crisis impact the results significantly.

Our results show that global demand and oil price shocks dominate as important external drivers of the Nigerian business cycle. Whereas, global demand shocks impact domestic output growth and inflation the most, oil price shock is found to exert considerable influence on the domestic interest rate and the terms of trade. Our robustness exercise show that, while the global demand shock has similar effects on domestic output growth and interest rate across the two samples, inflation volatility exhibits significant moderation when the data is purged of the global financial crisis. The results suggest that the macroeconomic risk associated with the global demand shock is a systematic one and thus, may not be diversifiable in small open economies. The observed oil price pro-cyclicality is preposterous for macroeconomic stabilization. Periods of financial crisis of a global scale will stretch central banks capacity to contain inflation among oil exporters. External shocks can be better managed if oil exporting small open economies utilize gains from positive global demand shocks to achieve high domestic growth rates, better infrastructures and improved productivity and competitiveness. On the other hand, managing oil price shocks require that SOE oil exporters pursue economic diversification to reduce oil dependency, accumulate fiscal buffers (savings) through the operation of a sovereign wealth fund and apply sound fiscal rules to dampen the effects of oil price shocks on business cycle fluctuations.

In chapter three, we present a multi-sector New Keynesian dynamic stochastic general equilibrium (DSGE) model featuring domestic and foreign production sectors. The representative domestic firm is assumed to be monopolistically competitive, hence subject to Calvo (1983a) pricing scheme; while a representative oil firm operate as a perfectly competitive firm. The SOE imports foreign final goods from the rest of the world (ROE) for consumption while the ROW combines the SOE's oil with a foreign intermediate good to produce foreign final good. We close the model with Taylor (1993)-type monetary policy specification. The model is calibrated to match standard small open economy characteristics and to reflect the broad features of an oil exporting emerging economy. A positive oil price shock is simulated on the model in order to analyse its dynamic effects on macroeconomic variables under alternative monetary policy specifications. We also conduct optimal monetary policy exercise given a range of loss functions that reflect central bank's preferences.

The results suggest evidence of Dutch disease, as non-oil and aggregate output fell in response to the shock. However, the significant increase in oil output compensates for the fall in non-oil output, resulting to higher employment and consumption levels. The exchange rate appreciates while interest rate falls in response to the Dutch disease, given there is no immediate inflation threat. Domestic inflation targeting policy rule is shown to be welfare-superior in the class of optimized simple rules while the commitment policy dominates both discretion and optimized simple rules.

In chapter four, we build a New Keynesian small open economy DSGE model which embed fundamental features of net oil exporting emerging economies. A representative oil firm produces crude oil exclusively for export to the rest of the world (ROW) while the household consumption basket and the non-oil firm's production function include imported refined oil. We assume nominal price rigidity in the domestic goods sector, a competitive labour market, the operation of the law of one price gap, a perfectly competitive, non-exogenous enclave oil producing sector, imperfect international risk-sharing, three alternative oil price pass-through specifications and a monetary policy setting that feature four alternative policy rules popular in most emerging and developing economies.

In the model, we capture fundamental features of net oil exporters, establish a direct connection between crude and refined oil prices and highlight seeming structural chasm between domestic oil and non-oil sectors in some net oil exporting countries. Given these characterizations, we simulate a negative oil price shock and analyze the consequent macroeconomic responses under alternative monetary policy specifications and oil price pass-through scenarios. Using optimized simple rules, we test for the welfare implications of implementing the alternative monetary policy rules under three oil price pass-through assumptions given the oil price shock.

In the aftermath of the shock, the economy experiences stagflation, which manifests via the income and exchange rate channels. In a zero oil price pass-through environment, the kind of target variable in the Taylor rule appear not to matter, as macroeconomic responses to the shock under all monetary policy specifications exhibit similarity, a development that suggests that oil subsidy interferes with monetary policy transmission mechanism under alternative specifications. Given perfect labour mobility, the negative oil price shock encourages movement of workers from the oil sector to the non-oil sector, thereby boosting non-oil productivity and output. The central bank responds to inflation and exchange rate pressures by raising the interest rate.

Macroeconomic fluctuations under partial and full oil price pass-through follow similar directional patterns as under the zero pass-through, but response speed and magnitudes are more pronounced under the former. Although, the monetary policy rule with oil inflation target is associated with less sharp impact response of oil consumption, aggregate consumption and aggregate output, it is characterized by slightly higher volatility over time, compared to other monetary policy rules. Monetary policy response was least aggressive on impact under oil inflation targeting rule but later turns aggressive as the initial fall in oil inflation reverses. Tight external borrowing condition adds an extra source of external vulnerability to the negative oil shock.

The optimized simple rules policy exercise show that either core or oil inflation targeting maximizes welfare in a full subsidy or zero pass-through scenario, while targeting oil inflation is shown to be welfare superior assuming partial or full pass-through. This modeling outcome presents a challenge in a rule-based interest rate setting environment, as the policy maker may jeopardize its credibility as it responds to movement in oil price, an exogenous and highly volatile variable. Our results suggest that oil subsidy can play a role in moderating adverse oil shock-induced business cycle fluctuations and can be welfare maximizing, assuming oil subsidy administration is efficient. Since oil inflation is too volatile to track, core inflation targeting seems the feasible optimal option for practical monetary policy purposes in oil exporting small open economies. Inherent external vulnerability can be managed through stronger domestic resilience to external shocks.

Chapter 2

External Shocks and Business Cycle Fluctuations in an Oil Exporting Small Open Economy

Appendix 6B: Statement of Authorship

This declaration concerns the article entitled:			
External Shocks and Business Cycle Fluctuations in an Oil Exporting Small Open Economy			
Publication status (tick one) Draft manuscript [x] Submitted [ ] In review [ ] Accepted [ ] Published [ ]			
Publication details (reference)			
Copyright status (tick the appropriate statement) I hold the copyright for this material [x] Copyright is retained by the publisher, but I have been given permission to replicate the material here [ ]			
Candidate's contribution to the paper (provide details, and also indicate as a percentage)	The candidate contributed to / considerably contributed to / predominantly executed the… Formulation of ideas: 100% Design of methodology: 100% Experimental work: 100% Presentation of data in journal format: 100%		
Statement from Candidate	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature.		
Signed	Sunday Oladunni	**Date**	25/09/2019

2.1 Introduction

The role played by external shocks in the evolution of countries business cycles is recognized in the literature. However, empirical questions still abound in oil exporting small open economies on the relative contributions of specific external shocks to the business cycle process. Each foreign shock affect countries in different ways, depending on the extent of each country's vulnerability, size of the shock and the active channels of transmission for the shock. A clear understanding of the strands of external shocks driving the business cycle is crucial for the formulation and implementation of appropriate macroeconomic policy responses. The knowledge of key business cycle-perturbing external shocks is particularly of interest to policy makers in oil-exporting small open economies, including Nigeria; in view of the important role oil export play in these economies. This argument is buttressed by the submission of Cashin & Sosa (2013), that an accurate identification and evaluation of sources of foreign disturbances and the mechanisms for adjusting to them is important for understanding business cycles dynamics and for designing appropriate policies to manage them. The impact an external shock has on the domestic economy will determine the choice, intensity and sequence of policy responses to such a shock.

Extant literature on Nigeria focuses overwhelmingly on the identification of individual foreign shocks, with huge concentration on oil price shock. For instance, Olomola & Adejumo (2006), Omisakin (2008), Umar & Kilishi (2010) and Ekong & Effiong (2015); amongst many others, zeroed in on oil price shock in their studies. The emphasis on oil-related shocks tend to obscure other potentially important external shocks to which the Nigerian economy may be susceptible. Thus, resulting in inaccurate inferences and inappropriate policy prescriptions. In order to address this, we adopt a unified approach achieved through block identification of three external shocks, namely: global demand, oil price and US monetary policy shocks. This modelling approach is particularly useful for disentangling the different external shock components affecting domestic business cycle movement. Through this approach, we can uncover the impact of each external shock and the corresponding relative contribution of each shock, over time, to the Nigerian business cycle.

This chapter aims to investigate the relative contributions of the three external shocks in the evolution of the Nigerian business cycle using sign restricted Bayesian structural vector autoregressive (SVAR) modelling technique. To our knowledge, this is the first attempt to apply this methodology on the Nigerian data to analyse a subject that has received limited attention in the oil exporting small open economy literature. The paper, therefore, represents an important addition to the applied macroeconomic literature in Nigeria and the wider oil exporting developing and emerging economies. The sign restriction identification procedure derives from

Olayeni (2009a), Adebiyi & Mordi (2012) and Allegret & Benkhodja (2015), in addition to the global macroeconomic literature in the spirit of Mumtaz & Surico (2009) and Kilian & Lewis (2011).

The results show that global demand shocks tend to impact domestic output growth positively for a long time. Similarly, domestic inflation exhibits high sensitivity to the global demand shock, while monetary policy tightens over longer horizon in response to the global demand shock-induced inflationary pressure. The sharp but short-lived response of terms of trade to the global demand shock stems directly from the positive response of oil price to the same shock, given the close link between the two variables in Nigeria. It is apparent from our results, that any shock that moves the oil price upward will elicit similar effect in the terms of trade, as oil export constitute a major component of the terms of trade. There is a delayed positive domestic inflation response to the US monetary policy shock, suggesting that monetary tightening in the US can elicit inflationary consequences in SOEs. This can be attributed to capital reversal in response to increased returns in the US and flight to safety and quality. The lag in inflation response, however, may reflect investors cautious attitude or potential temporary constraints to capital mobility.

In addition, the US monetary policy shock exerts a moderate and negative effect on the domestic output growth in our model; indicating that world monetary policy does matter for macroeconomic stabilisation in Nigeria. The oil price shock does not cause inflation on impact; rather, it contributes to inflationary momentum over time. This result captures how oil boom often result to immediate improvement in external reserves position and exchange rate appreciation. However, with time, the boom induces decline in competitiveness, higher demand for imported goods and excess domestic liquidity which often fuel exchange rate and inflationary pressures, that may compel the central bank to tighten policy stance. Overall, the global demand and oil price shocks are revealed to exert significant influence on domestic output growth and the most discernible effect on inflation compared to the US monetary policy shock. The result indicates that the global demand shock is the prime mover of business cycle fluctuations in Nigeria. Our robustness exercise which covers the pre-crisis period of 1982Q2 - 2007Q4 show that, whereas global demand shock had similar effects on domestic output growth and interest rate, inflation volatility moderated significantly. Thus, suggesting that the global financial crisis contributed to higher inflation volatility in Nigeria.

Section 2 presents a survey of the literature and section 3 explores the methodology; while section 4 treats data, model and estimation. Section 5 presents and discusses the results while section 6 concludes the paper.

2.2 Some Stylized Facts

The global economy is a network of trading countries, with the United States (US) as the only one with requisite market power to significantly influence global market conditions. Other countries are considered as small open economies whose individual market power is not sufficient to influence world prices, the global term structure and international income levels. Trade relations among economies account significantly for the increasing integration of many economies. Each country's role in the complex global economic interactions is to a large extent determined by the size of their individual markets, factor endowments, financial infrastructure, technology and development status, among others. Such trade dynamics places the U.S. in a vantage position to influence global market conditions and other players adjusts from time to time to the external shocks vulnerabilities imposed on them. Typically, economies with diversified production base and high levels of self-sufficiency tend to exhibit less sensitivity to external shocks except when such phenomena are of a global scale or the channels through which such shocks affect the economy is prominent. Conversely, developing and emerging economies, especially those relying on primary product exports as the main source of government revenue and foreign exchange are often highly susceptible to volatility in global commodity market conditions.

Many oil exporting small open economies like Nigeria, have been through economic twists and turns occasioned by oil price oscillations, changes in the global economic conditions and monetary, fiscal, financial and other developments in their trading partners economies. Oil price increases often result in higher government revenues and expenditure, economic growth, external reserves growth, exchange rate stability, higher capital inflows and improvements in the balance of payments. During oil boom, the exchange rate is often over-valued, encouraging increased importation and leading to decline in non-oil export competitiveness. This scenario is known as the Dutch disease[1]. However, a sustained fall in oil price often precipitate sharp decline in government revenues, high budget deficits, higher public debts, inflation up-tick, slide in economic growth, threat of recession, increase in trade arrears, external reserves depletion, exchange rate depreciation, capital reversal, balance of payments crisis, rising unemployment and poverty, industrial crises and general macroeconomic instability.

Volatility in the price of primary commodities often reflect in the pattern of resource endowed and commodity exporting countries business cycles. Business cycles in mono-product or primary-led economies often co-vary with movements in the global market conditions for the products they export. Whereas, primary com-

[1]See Egert & Leonard (2008) and Benkhodja (2014)

modity importing countries reap huge benefits from an oil price fall and face higher input costs when price rises, the experience of commodity exporters is different. For the latter, periods of decline in price are usually austere while wind-falls come with upward trending prices. Similarly, economies with ample potential for attracting foreign capital flows often become vulnerable to events[2] in the investors home countries. Such events may trigger a swift, herd-like exit[3] from other markets where they had interests either due to maturing obligations at home or for safety considerations. Thus, giving rise to the disruptive phenomenon of sudden stops[4] in many developing and emerging economies with high returns on investments.

Since the 1950s, Nigeria has been a primary-led economy; shifting overtime from reliance on agriculture to oil for government revenue and foreign exchange earnings. About 85 percent of Nigeria's foreign exchange earnings is derived from crude oil sale receipts while about 70 percent of government revenue is derived from the same source. The continual over-reliance on oil, the high orientation towards importation of consumer products and the failure to diversify the economy expose the country to the consequences of an adverse external shocks. The contagion effects of the global financial crisis (GFC) of 2008/09, US quantitative easing (QE) and subsequent QE tapering on many emerging and developing economies underscore the crucial role external shocks play in their business cycle evolution. The GFC effects reverberated through the Nigerian financial markets after a short lag. For instance, the Nigerian All-Share Index (ASI) fell from 65,652.38 points in February 2008 to 19,851.89 points in March 2009; representing a loss of about 70 percent. Also, external reserves came under intense pressure, dropping from \$62.08 billion in September 2008 to \$31.89 billion in June 2011, representing a decline of about 50 percent. These events tended to mirror the decline in the oil price which stood at \$137.74/barrel in July 2008 and \$44.95/barrel in January 2009, respectively. The inflow of foreign portfolio investments (FPI) into Nigeria dipped remarkably during the crisis. The Nigerian banking sector's experience was particularly grave, as non-performing loans rose and toxic assets in banks balance sheets eroded their capital base substantially. In response, the central bank pursued an accommodating monetary policy by reducing the policy rate from 10.00 percent to 6.00 percent and implemented quantitative easing measures to promote credit flow in the economy. Also, to address the concern about financial system stability, the Bank injected funds into some ailing banks in form of Tier II capital and set up a crisis resolution vehicle, namely the Asset

[2]These are dramatic macroeconomic or financial developments that may cause international investors to repatriate capital or readjust their investments portfolios offshore

[3]This refers to foreign investors divestment from an economy owing to worsening macroeconomic outlook in that economy or shocks from their home and other countries

[4]This is a crisis triggered investor behaviour resulting in phenomenal seizure in the flow of capital into a country or reversal of capital from a country.

Management Corporation of Nigeria (AMCON) to buy up banks toxic assets and repair their balance sheets.

Figure 2.1 shows movement in the quarterly world output growth, domestic output growth and domestic inflation rates between 2001Q1 and 2016Q1.

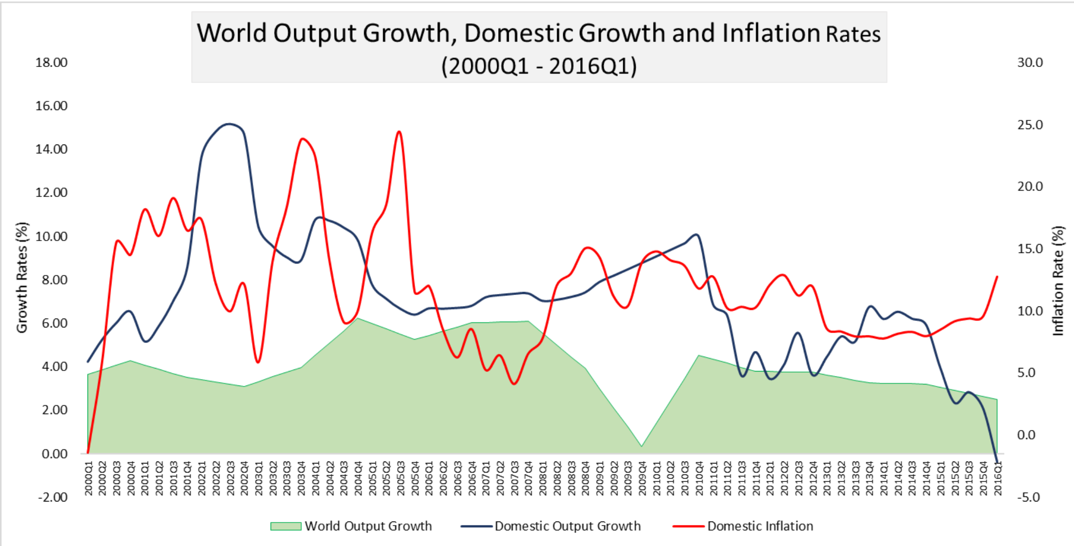

Figure 2.1: World Output Growth, Domestic Growth and Inflation Rates

Over the period, world output growth had been positive and fairly stable around an average of 3.0 percent. The worst performance for global growth was experienced late 2009 at 0.34 percent. This is due to the impact of the global financial crisis of 2008/09 which resulted from a world-wide credit crunch. It is observed that, the GFC-induced low global growth did not affect Nigeria's growth performance immediately. The effect, however, became manifest after a three quarter lag; suggesting that spill-over effect may be stronger than contagion effect in Nigeria. This may also justify the possibility of the trade channel being stronger than the financial channel in Nigeria. Domestic inflation rate is high and mostly in the double-digit range over the period. Domestic output and inflation are shown to move in nearly opposite direction. A classic example of this is between 2015Q1 and 2016Q1 when domestic output growth and inflation moved in sharply opposite directions; with output decelerating into negative territory as inflation sky-rocketed. This is a clear case of stagflation, a challenge that has remained daunting for policymakers in Nigeria.

Figure 2.2 shows trend in oil price, domestic growth and inflation between 2001Q1 and 2016Q1. The chart suggest that oil price and inflation are more volatile, and tend to co-move on the average. Domestic output growth assumes a unique and less volatile trend; and does not share strong co-movement with oil price. However, both oil price and domestic growth exhibit strong co-movement between 2014Q3 and 2016Q1. This indicates that the co-movement between oil price and domestic growth is asymmetric; as it is more visible when oil price is on a downward path. This trend,

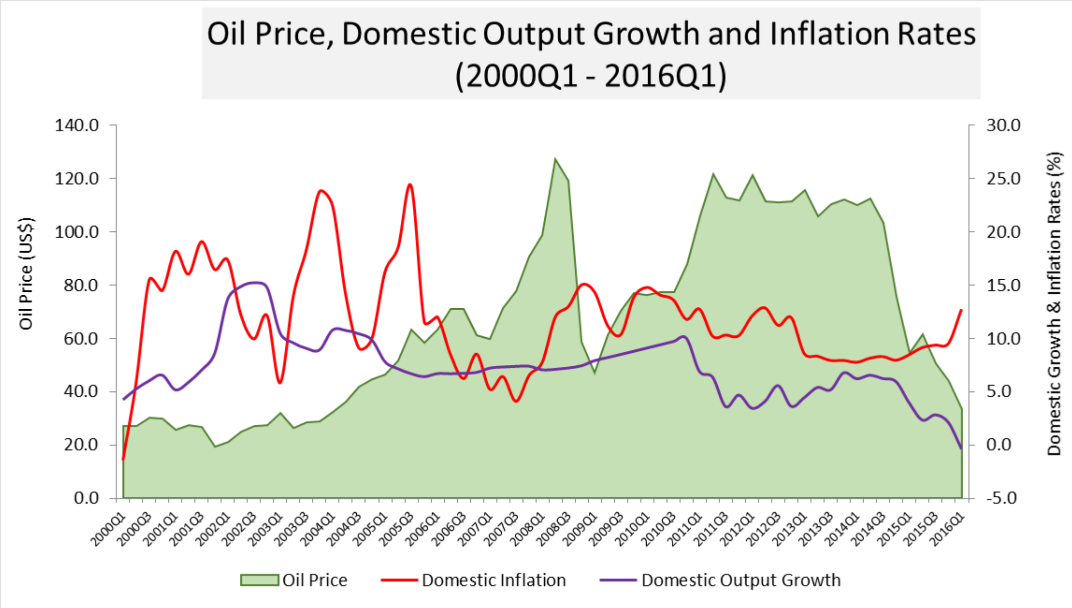

Figure 2.2: Oil Price, Domestic Growth and Inflation Rates

when linked with the observed rising inflation during the period, indicates that fall in oil price is stagflationary in Nigeria.

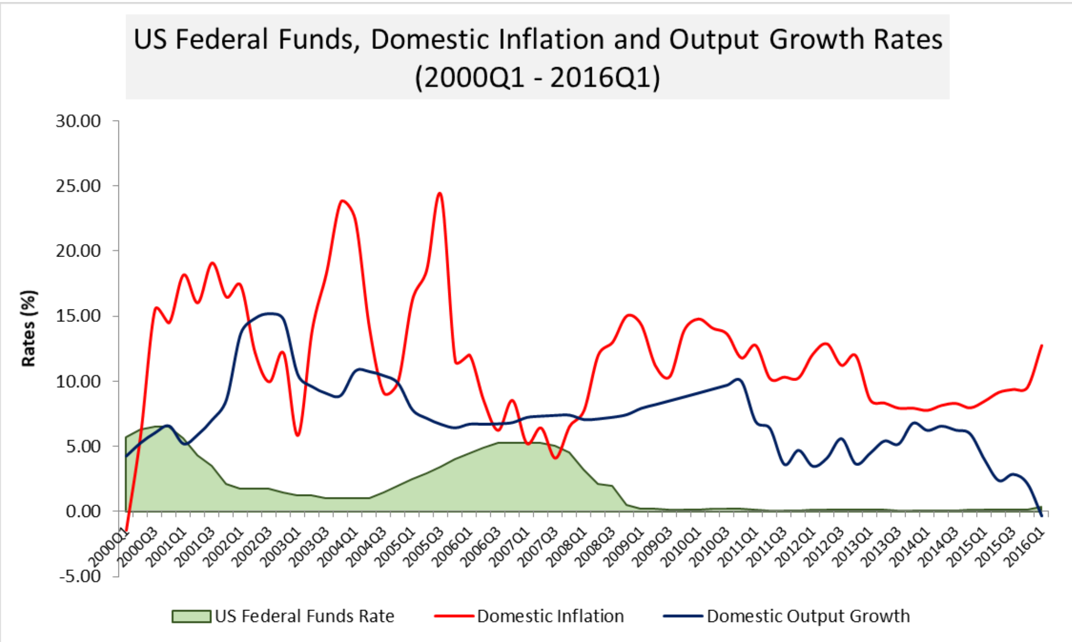

Figure 2.3: US Federal Funds, Domestic Inflation and Growth Rates

Figure 2.3 shows movement in the US federal funds rate, domestic output growth and inflation. Overall, this chart does not indicate significant patterns between federal funds rate and domestic variables. However, there is a slight indication that Nigeria's output performance is somewhat improved as foreign interest rate falls. This observation is buttressed by the recent trend whereby low interest rate environment in developed economies encourages capital flows into emerging market economies with high interest rates. An emerging economy with high inflow of foreign capital can leverage such for economic growth.

In table 2.1 key external and domestic macroeconomic variables are presented based on the average for each decade since 1982. It shows some preliminary evidence of possible interactions between global macroeconomic dynamics and domestic business cycle in Nigeria.

Variables	External			Domestic	
Period	World Output Growth (%)	US Fed Funds Rate (%)	Oil Price (US$)	Inflation Rate (%)	RGDP[5] Growth Rate (%)
1982Q1 - 1990Q4	3.06	8.67	23.46	23.88	2.80
1991Q1 - 2000Q4	3.15	4.96	19.20	32.21	2.08
2001Q1 - 2010Q4	4.29	2.35	55.91	13.00	8.74
2011Q1 - 2016Q1	3.43	0.13	95.11	9.83	4.57

Table 2.1: Selected External and Domestic Macroeconomic Indicators

For instance, in the period 2001Q1 - 2010Q4, world output growth and domestic output growth peaked at 4.29 percent and 8.74 percent, respectively. Whereas, in the preceding decade, the world recorded the second lowest output growth of 3.15 percent while Nigeria recorded its lowest output growth at 2.08 percent in the same period. As can be observed from the table, domestic inflation was subdued and real gross domestic product tend to perform better in a global environment with higher oil prices. These tend to suggest that developments in the global economy do have significant influence on the Nigerian economy, working mainly through the exchange rate channel.

Table 2.2 shows the results of cross correlation analysis implemented on the dataset. It shows the direction and strength of the association that exist among the variables under consideration. The degree of association between oil price and terms of trade is the strongest in the dataset at 46 percent. This is not surprising as oil export represent the principal component of Nigeria's total exports.

[5]Real Gross Domestic Product

Variables	GOG	FFR	OPG	DOG	INF	TOT	DIR
GOG	1.000	-0.061	0.130	0.406	-0.462	0.171	-0.285
FFR	-0.061	1.000	0.037	-0.408	0.134	0.007	0.091
OPG	0.130	0.037	1.000	0.175	-0.071	0.457	0.099
DOG	0.406	-0.408	0.175	1.000	-0.425	0.092	0.176
INF	-0.462	0.134	-0.071	-0.425	1.000	-0.064	0.411
TOT	0.171	0.007	0.457	0.092	-0.064	1.000	0.087
DIR	-0.285	0.091	0.099	0.176	0.411	0.087	1.000

Table 2.2: Correlation Analysis of the Data

Table 2.3 shows the descriptive statistics of the data[6]. It indicates that the distribution of four out of the seven variables satisfy the normality assumption while three did not. Oil price growth and inflation exhibit the highest level of volatility in the dataset.

	GOG	FFR	OPG	DOG	INF	TOT	DIR
Mean	3.509	4.358	1.159	4.605	21.03	0.012	11.97
Median	3.476	4.838	1.081	5.003	13.28	-0.489	11.72
Maximum	6.226	14.51	65.82	15.18	89.56	33.89	27.00
Minimum	0.338	0.073	-50.56	-8.061	-4.976	-31.66	4.630
Std. Dev.	1.281	3.252	14.87	4.480	19.66	8.233	4.306
Skewness	0.052	0.292	0.171	-0.332	1.430	0.393	0.979
Kurtosis	2.761	2.404	5.943	3.482	4.195	7.124	4.103
Jarque-Bera	0.384	3.953	49.75	3.824	54.48	99.91	28.64
Probability	0.825	0.138	0.000	0.147	0.000	0.000	0.000
Sum	477.2	592.7	157.7	626	2860	1.705	1628
Sum Sq. Dev.	221.5	1428	29877	2709	52206	9151	2503

Table 2.3: Descriptive Statistics

[6] GOG is global output growth, FFR is US federal funds rate, OPG is oil price growth (Bonny Light Oil price changes), DOG is domestic output growth, INF is domestic inflation, TOT is terms of trade and DIR is domestic interest rate. See List of Acronyms.

2.3 Literature Review

2.3.1 Theoretical Literature

Mitchell (1927) and Burns & Mitchell (1946) characterize business cycles as "a type of fluctuation found in the aggregate economic activity of nations that organize their work mainly in business enterprises: a cycle consists of expansions occurring at about the same time in many economic activities, followed by similarly general recessions, contractions and revivals which merge into the expansion phase of the next cycle; this sequence of changes is recurrent but not periodic; in duration business cycles vary from more than one year to ten or twelve years; they are not divisible into shorter cycles of similar character with amplitudes approximating their own" (Skare & Stjepanovic (2016)). From this foundation, business cycles may be regarded as the regular periods of expansion and contraction in major economic aggregate variables like employment, industrial production, export, output, consumption, investments, prices and interest rate. In terms of duration, the U.S. National Bureau of Economic Research (NBER) estimates that an average business cycles last from 4 – 6 years in the U.S.

Both external and domestic shocks are known to play important role in business cycle fluctuations. Rebelo (2005) notes that the Great Depression may have been caused by a strange mix of bad shocks and policy, with shocks like large drops in world agricultural products, acute drought and financial system instability topping the list. Important shocks that have been identified as drivers of the business cycles in the literature include technology/productivity shocks (Prescott, 1986; Norrbin & Schlagenhauf, 1988; Nelson & Plosser, 1982; King & Rebelo, 1999), fiscal shocks (Baxter & King, 1999; Braun, 1994; and McGrattan, 1994), changes in government spending (Ramey & Shapiro, 1998, Burnside, 1996 and Fisher, 2003), monetary shocks (Bernanke *et al.*, 1996), energy price shocks (Kim & Loungani, 1992a; Rotemberg & Woodford, 1996; and Finn, 2000). In open economies, external shocks such as oil price shocks, terms of trade shocks, foreign monetary policy shock, global demand shocks etc tend to play crucial roles in shaping movements in the business cycles.

The International Monetary Fund (IMF) in Varangis Panos & Nehru (2004) considers a shock as deviation from a normal, expected trend that is unanticipated or exogenous. It is an unforeseen event, outside the control of authorities, which has significant impact on the economy and requiring response or adjustment. Germane questions arising from this definition include: (a) which shocks can be considered as purely exogenous and (b) what constitutes significant impact? Varangis Panos & Nehru (2004), in response note that pronounced shocks occurring suddenly, such as natural disasters (for example, earthquakes, hurricanes) can be quite different compared to those that unfold slowly (such as commodity prices, droughts). The first is easier to identify, with duration that can be ascertained with some measure of accuracy and on a scale that can be assessed with some confidence; while the second type that unfolds slowly, usually starts unnoticed, and with impact that are hard to assess. They identify another shocks categorization, namely; input shocks and output shocks. An input shock relates to the source of the disturbance to an economy. These may include terms of trade shock or a natural disaster. An output shock touches on the impact of the disturbance measured as trend deviation in output or export earnings. A consumption shock will measure the impact on trend deviation in consumption. The process by which input shocks are translated into output shocks is known as transmission mechanism, which to a large extent is determined by the structure of the economy, institutional quality and the policy environment.

Also, shocks have been characterized as temporary changes in the conditional mean of stochastic processes feeding a particular model. Shocks, as discussed in the real business cycle (RBC) model a la Kydland & Prescott (1982) analyses the consequences of changes in the conditional mean of productivity (i.e. productivity or technology shock). Woodford (2003) and Christiano *et al.* (2005) analysed shocks as the effects of temporary changes in the conditional mean of innovations to the nominal interest rates (i.e. monetary policy shock). Mendoza (1991), Neumeyer & Perri (2005) investigated shocks associated with temporary changes in the condition mean of the real interest rate, while Mendoza (1995) probed temporary changes in the first moment of the terms of trade (i.e. terms of trade shock). In recent times, macro-economists have shown interest in scenarios where shocks are associated with temporary changes in the conditional second moments (standard deviation) of the stochastic process, rather than the first moments (mean). This has been referred to as stochastic volatility or time-varying standard deviations.

In the macroeconomics literature, supply shocks can be distinguished from demand shocks. Supply shock, generally refers to a sudden and significant deterioration in the aggregate supply position in a country, which disturbs the structural balance of the economy, leading to increased prices and unemployment. This type of shock may be caused by a sudden fall in the supply of raw materials or/and a rise in input prices, say for example a significant rise in oil prices resulting in a decline in output, a rise in unemployment and rise in inflation. This is such that create policy dilemma for the authorities, who may either in line with classical prescriptions wait for the very 'long run' for equilibrium to be restored or intervene through fiscal or monetary expansion to boost employment, and then live with or manage the possible inflationary consequences. In the old Keynesian sense, however, a demand shock is said to capture a temporary shift in consumer expectations as an exogenous disturbance to the IS equation which does not generate positive co-movement between inflation, employment and output (Lorenzoni, 2006).

Several studies have indicated the role that external shocks play in influencing macroeconomic conditions in emerging and developing countries.UNCTAD (2002), Raddatz (2005) and Berg *et al.*, 2011 underscore the fact that exogenous shocks often exert significant negative impact on developing economies growth, stability and welfare. They emphasize that poor countries are particularly vulnerable to natural disasters and terms-of-trade shocks. Thus, it is believed that world commodity prices' levels and volatility constitute important influence on economic growth and welfare in less-developed countries. Vegh (2013) notes that external shock may be decomposed into two (2) strands, namely: (a) external nominal shocks, which represent changes in foreign inflation rate; and (b) external real shocks, which is regarded as shocks to terms of trade.

The channels through which external shocks are propagated is key to understanding the sources, nature and magnitude of impact of shocks in any economy. Chowla *et al.* (2014) submits that a good grasp of shocks transmission channels is important, given that such knowledge can help policymakers to either limit or offset the impact of shocks. Three main external shocks transmission channels have been identified in the literature. The first is the external trade channel. It works via the income effect on demand. A negative foreign demand shock, ceteris paribus, will lower international demand for exports. The shrinkage in exports lowers export earnings, dampens domestic employment, causes exchange rate depreciation and raises the possibility of a recession or depression in many trading countries. However, in case of a supply shock, say for instance, "an act of God" which cause huge decline in a major production input, there will be pressures on firms inputs costs, leading to a cost push inflation across borders. The effects of these shocks often work through other countries that the world rely on for trade purposes.

The second is the financial channel, which is often reflected through improved global liquidity flows in good times and tight credit conditions and higher asset price volatility in periods of financial stress. Whereas, the trade channel work through exchange of goods and services, the financial channel is underlined by the exchange of financial assets, across different jurisdictions. The financial channel may be subdivided into three, namely: (a) credit channel, (b) funding channel and; (c) non-banking channel. The credit channel work through domestic financial institutions' exposure to foreign counterparts or through foreign subsidiaries. Domestic economic agents can be adversely affected when the risks associated with domestic banks' exposure to foreign banks or when banks' foreign exposures through offshore subsidiaries crystallizes. This may be thought of as the risk a local bank faces as a result of losses originating from her foreign subsidiaries. Losses experienced by banks' foreign subsidiaries through higher non-performing loans due to slow-down in economic activities in the foreign country where they operate. These trends tend to impact negatively on affected home banks' capital base and their capacity to sustain or expand their balance sheet through new loans, thus, leading to a credit crunch.

The funding channel operates through dependence of home financial institutions on funding from offshore sources. Many domestic banks which have credit lines with foreign banks may have such facilities discontinued or reduced when foreign banks are faced with liquidity squeeze of a significant magnitude. This will affect funding for international transactions and business operations of domestic banks customers. Generally, during financial crisis or boom of a global dimension, cross-border lending activities are usually strongly affected. Chowla *et al.* (2014), following a study on the UK, submit that strong evidence exist to indicate that both the funding and credit channels are crucial for the transmission of global shocks to the UK economy during the 2008/09 financial crisis.

The non-banking channel addresses the transmission of external shocks through domestic ownership of foreign assets and liabilities by the non-bank public. Participation in foreign direct and foreign portfolio investments in other countries can have significant impact on investors through 'wealth effect' in case of a major shock in the recipient economy. Offshore losses incurred by households and firms through their foreign portfolio positions may lead them to cut spending domestically, and for the foreign countries, it may lead to capital reversals that may snowball into a 'sudden stop'.

In addition to the trade and financial channels, the uncertainty channel can also amplify foreign shocks in the local economy. Uncertainty normally arise when agents are pessimistic or less optimistic about the outlook for domestic or/and global macroeconomic conditions. Bernanke (1983) and Bloom (2009) also submit that economic agents tend to defer their spending decisions in periods when macroeconomic prospects are shrouded in uncertainty. Firms, in particular, tend to postpone investment when the macroeconomic outlook is adjudged unfavourable. High uncertainty may also precipitate higher costs of fund for firms and households as the market rate of return rises to compensate against future risks.

The literature posits that many cross-border shocks transmission occur through contagion and spill-overs effects. Kaminsky & Schmukler (2003) provide a distinction between contagion and spill-over. A contagion is thought of as an episode which produce significant immediate effects in a number of countries following a shock, whose consequences are fast and furious and evolve over a matter of hours or days. In the case of spill over, the initial international response to the shock may be muted, but it becomes manifest in a gradual and protracted manner, with potential cumulative economic consequences. They exclude common external shocks, such as global interest rates changes or oil prices in their working definition of contagion, with the exception that an excess co-movement in financial and economic variables exist across countries in response to a common shock. The extent to which an external shock operate depend largely on the economy's degree of openness and level of integration with major trading partners and the global economy. External shocks propagation is usually weaker for countries that are less integrated with the rest of the world. The farther an economy is from being fully open, the less susceptible it is to contagion and spill over effects.

2.3.2 Empirical Literature

The literature provides evidence on the effects of external shocks on small open (oil exporting and non-oil exporting) economies. While many studies find external shocks to be the major diver of business cycle fluctuations, others report that the role of domestic shocks is stronger on specific business cycle variables. In the case of Australia, Dungey *et al.* (2002), based on a SVAR model attributes only 32 percent of the variations in output forecast errors over a twelve-month horizon to external shocks while domestic demand shocks dominates in moving the business cycle. Contrary to Dungey *et al.* (2002), Nimark (2007) based on the results of an estimated New Keynesian dynamic stochastic general equilibrium (DSGE) model submits that external shocks explains more than half of the variance in output while domestic demand shocks account for just 8.0 per cent. Also, Dungey & Pagan (2000), with a simulated data from a SVAR model, find that economic downturns in Australia would have been mild had there been no shocks from foreign sources, and total volatility during economic expansion would have been less pronounced.

Similarly, Liu (2010) extracted the cyclical component of Australia's GDP series using the Beveridge-Nelson decomposition and set up a SVAR model identified with sign restrictions obtained from a small open economy DSGE model in the spirits of Monacelli (2005) and Gali & Monacelli (2005), and showed that foreign shocks provide more than 50 percent of total explanations for Australia's output fluctuations, while the impact of domestic demand shocks on the business cycle is found to be rather muted. Leu (2011) built a SVAR model based on exclusion restrictions gleaned from an estimated open economy New Keynesian model which capture the rational and forward looking attributes of economic agents. The findings reveals that the Reserve Bank of Australia care much about short-run output stabilization and medium-term target for inflation; while external dynamics are found to impact significantly on aggregate demand shocks in Australia. Sariola (2015) investigates the structural shocks driving the Swedish business cycle, using a sign restricted SVAR, identified four (4) shocks based on guidance from Riksbank's DSGE model (known as Ramses II) by Adolfson & Walentin (2013). The results indicate that nearly half of the volatility in the Swedish output is accounted for by productivity and external demand shocks; while the contribution of domestic demand shock to output volatility is negligible.

The notion that external shocks do impact notably on emerging and developing economies is further strengthened by Calvo *et al.* (1993), who apply a SVAR model and find that foreign shocks account for a significant share of the variance in the real exchange rate in the period 1988 – 1991 in Latin America. Broda & Tille (2003) in a study covering seventy five (75) developing countries across Asia, Africa, Latin America and Eastern Europe, investigated how terms of trade can affect a country's real income, price level and exchange rate, using the VAR methodology. They find that a large proportion of output volatility in developing countries can be attributed to changes in the terms of trade. Mendoza (1995) employed a three-sector inter-temporal equilibrium model to investigate the nexus between terms of trade and macroeconomic fluctuations in small open economies. Results from the study indicates that about 50 percent of actual GDP variability is due to terms of trade shocks, but the correlations between net export and terms of trade was found to be weak. Canova (2005) studied the transmission shocks to eight Latin American countries from the U.S., by identifying U.S. shocks as exogenous using the sign restrictions SVAR technique. The paper captures both contemporaneous and lagged effects through a bilateral specification in which each Latin American country is paired with the U.S. This approach is said to remove from the analysis the possibility of feedbacks among Latin American countries or through third party countries. Findings from the study demonstrate empirically that, while the U.S. monetary shocks results in significant fluctuations in Latin American business cycles and that both real supply and demand shocks do not have significant effects on the region's business cycle. Also, within the Latin American region, the distinction between countries which operate the floating exchange rate system and those with currency boards did not matter much. The financial channel for shocks transmission is found to be crucial.

In a study which employs a four variable SVAR, Huang & Guo (2006) identify global foreign shocks as a global supply shock, and utilizing data over the period 1970 - 2002, finds external innovations to be significant, with positive correlation among the countries in East Asia. Ng (2002), in a study of five emerging countries in South Eastern Asia spanning the period 1970 - 1995, identified one external shock and two domestic shocks using a SVAR. Findings from the study indicate that the response of domestic variables to external shocks across these countries is strong. Thus, providing some empirical justification for the establishment a monetary union in the region. In a related study on small Asian economies, Genberg (2005) estimated a VAR model to investigate the effects of external shocks on these countries and finds that foreign shocks from the U.S., rather than China, mainly account for the inflation dynamics in the six Asian economies of Hong Kong, Thailand, Singapore, Korea, the Philippines and Taiwan.

In a related study on emerging market countries, with a SVAR model that reflect block exogeneity over the period 1986M1-2000M12, Mackowiak (2007) used world commodity prices, the US Federal funds rate, the U.S. aggregate price level, the U.S. money stock and the U.S. aggregate output as external shocks. Results from the study suggest that all external shocks apart from the U.S. monetary policy shock affect domestic variables significantly in these economies. Also, the study underscores the tendency for external shocks to be persistent, as they are shown to contribute more to fluctuations in emerging economies' domestic variables at longer forecast horizons. Similarly, Sato *et al.* (2011) examine the contributions of external shocks to fluctuations in East Asian countries' business cycles, with a SVAR model that applied block exogeneity to achieve identification in line with the small open economy assumptions. Estimation is conducted for three sub-samples: 1978Q1-1987Q4; 1988Q1-1996Q4; and 1999Q1-2007Q4 to detect dynamics inherent in each episode of external shocks, as well as the business cycle dynamics of East Asian countries. Findings from the study indicate that external shocks of the U.S. and those of Japanese origin were prominent in East Asian countries prior to the financial turbulence of 1997 – 1998. After the crisis, however, while the U.S. shocks still dominate as the main source of fluctuations in rest of East Asia, China's main vulnerability is to Japanese shocks.

Gimet (2011) juxtapose two crises episodes, namely; the Asian crisis (1997M1-1999M12) and the sub-prime crisis (2007M1-2009M12) to examine the susceptibility of East Asian economies to world-wide financial turmoil, using a structural Bayesian vector autoregressive modelling framework. Results from the study reveal that over time, East Asian economies' financial vulnerability has reduced, however, responses to global shocks remain non-symmetric, given that positive and negative shocks do not result in equal amount of effects. Utlaut & Van Roye (2010) analysed the effects of external shocks on Asia's emerging economies through through Bayesian VAR estimation and show that nearly half of drivers of emerging Asia's real GDP growth rate is attributable to external innovations. They simulated a double dip situation in the global economy, with a subdued growth path in China based on conditional forecasts, it was discovered that the global economic growth trajectory dictates significantly emerging Asia's economic outlook and not the Chinese business cycle fluctuations. Silva (2012) explores the role domestic and external shocks play in driving business cycles in Mexico and Brazil. In the paper, non-recursive contemporaneous restrictions and block recursive restrictions were imposed and Bayesian estimation was implemented. Results from the exercise reveal that for both Brazil and Mexico, domestic shocks are the prime drivers of domestic output at shorter horizons while external shocks predominates at longer horizons. Among the external shocks, U.S. output shocks, compared to the U.S. monetary policy shocks, exerts greater influence on domestic output volatility. Also, Silva (2012) finds that while commodity price shocks account for nearly 18 per cent of the output volatility in a 2-year horizon in Brazil, it accounts for about 20 percent in Mexico in the same time horizon.

Houssa *et al.* (2015) for a study on Ghana, a low income country with small open economy, examine, using a mix of sign and recursive restrictions in a Bayesian VAR modelling framework, the role international and domestic shocks play in shaping business cycle evolution in Ghana. The same exercise is replicated for South Africa, an economy with a similar structure but at a higher stage of development, to provide a benchmark. They pair macroeconomic dynamics in the G-7 countries with Ghana and South Africa, respectively; and finds that world productivity and credit shocks dominates more in South Africa than in Ghana, while commodity shocks is discovered to be a major factor in both countries' business cycles. Global credit market shocks exert no notable influence on Ghana while productivity shocks do, suggesting that Ghana's integration with the global economy works more via trade channels and less via financial channels. Their findings underscore the need to recognize the role of the primary goods sector for policy purposes in commodity exporting countries.

Rafiq (2011) assumes a small open economy condition to investigate sources of economic fluctuations in oil-exporting countries and implications for exchange rate regime choice using a sign restricted SVAR. Shocks were identified based on "textbook economic theory" and the results indicates that international shocks (i.e. terms of trade shocks) impact on exchange rate and domestic price movements more than domestic shocks in oil-exporting emerging market economies. A robustness exercise in which the terms of trade variable is replaced with oil price yields a similar result, except that oil price shocks exerts greater influence on exchange rate fluctuations. In addition, results of the robustness exercise also suggests that most of the volatility in the terms of trade in emerging market oil exporting economies are due to oil price changes.

Olomola & Adejumo (2006) examined the effect of oil price shocks on inflation, output, the real exchange rate and money supply in Nigeria using ordinary VAR, and finds that the direct impact of oil price shocks on inflation and output is subdued. Whereas, inflation is influenced by output and the real exchange rate shocks, oil price shocks impact significantly on the real exchange rate. The results also reveal that oil price shocks pass-through in Nigeria operate via the real exchange rate and money supply, respectively. Philip & Akintoye (2006), Christopher & Benedikt (2006) and Omisakin (2008) are unanimous in their conclusions that oil price shock has no significant effect on domestic variables like money supply, government expenditure, output and inflation . However, Umar & Kilishi (2010) using a VAR methodology finds that oil price has significant effects on real output, unemployment and money supply; while the effect is not found to be significant for the consumer price index. Similarly, Akpan (2009), also using the VAR framework, reports that exchange rate, inflation and output exhibit significant sensitivity to oil price movement in Nigeria. Alege (2015) characterize the Nigerian business cycle using the Dynamic Stochastic General Equilibrium (DSGE) model in the spirits of Nason & Cogley (1994) and Schorfheide (2000); extended to incorporate the export sector with a view to reflecting the transmission mechanism of terms of trade. Results from the study show that the Nigerian business cycle is driven by both real and nominal shocks.

The effects of external shocks as observed with small open economies in Asia, Latin America, Middle East and Africa is not the same with the G-7 countries. For instance, Kim (2001) [7] finds insignificant spill-overs of U.S. monetary policy shocks to the G-7 countries. This results provide some degree of corroboration for the later findings by Mackowiak (2007), which suggests that the emerging market economies tend to exhibit greater susceptibility to external shocks compared to advanced economies. More recently, Huh & Kwon (2015) estimate a Bayesian SVAR model of the real exchange rate, output and trade balance for the G-7 with a set of sign restrictions derived from Clarida & Gali (1994)'s stochastic rational expectations open-economy model with sticky prices. They extend the model by incorporating trade balance and identifying supply shocks using the implied long-run restrictions of the output-neutrality condition. Their results show that nominal shocks tend to induce real exchange rate depreciation and lead to improvements in the trade balance in the long run across G-7 economies.

[7] The G-7 is the group of seven leading advanced economies in the world including the U.S., Canada, France, Germany, Italy, Japan and the U.K.

2.4 Methodology

Generally, VAR models are known to forecast and describe dependencies among variables well. Since Sims (1980)'s popularization of this class of models, they have become increasingly useful among macro-economists and researchers in policy institutions for policy analysis. VAR models have been part of the foremost working tools in applied macroeconomics (Christiano *et al.*, 1998; Canova, 2005; and Lütkepohl, 2013). They tend to fit macroeconomic data well and are very useful for capturing the dynamic effects of shocks or responses to shocks in a given system of variables.

Typically, a VAR specification requires that each variable is expressed as being determined by its own lagged values and the lagged values of other variables in the system. Important outputs of the VAR models include impulse response functions, variance error decomposition and historical decomposition. A VAR(p) process is of the form:

$$y_t = A_i y_{t-i} + e_t, \qquad t = 1, ..., T \tag{2.1}$$

where y_t is $(nx1)$ vector of endogenous variables in the model; A_i are (nxn) matrices of coefficients, for $i = 1, ..., p$; and, e_t represents $(nx1)$ vector of unobservable white noise processes with $E(e_t) = 0$, constant and positive-definite covariance matrix $E(e_t e_t') = cov(e_t) = \Omega_e$. The errors (e_t) have zero auto-correlation but may be correlated across equations. This possibility of cross equations correlation tend to undermine the plausibility of extracting valid economic intuitions from the reduced form VAR models.

Despite their popularity, VAR models are purely statistical. Therefore, to make meaningful economic inferences from the VAR estimates, plausible economic structures are normally imposed on the unrestricted VAR system. Thus, it is often the practice to identify a given structure on the reduced form VAR to insert some elements of economic theory into them for informed policy analysis.

2.4.1 From structural VAR to reduced form VAR

Whereas, in the unrestricted VAR, only predetermined variables are specified on the RHS[8] as in 2.1 above, structural VAR allow for contemporaneous interactions among variables. Typically, the expression for a (stationary) structural VAR of order 1 can be of the matrix form:

$$B_0 y_t = B_i y_{t-i} + \epsilon_t \tag{2.2}$$

[8]RHS: right hand side of an equation

Matrix B_0 is the contemporaneous impact matrix, which summarizes the instantaneous interactions among the variables; B_1 is (nxn) matrix of coefficients of the model dynamics. The first feature which distinguishes the structural VAR from the unrestricted VAR is the addition of the impact matrix B_0, and the second, is the replacement of the reduced form errors or residuals, e_t by an $(nx1)$ vector of structural shocks or unobservable zero mean white noise processes ϵ_t. This property ensures that ϵ_t are serially uncorrelated and independent of each other such that the variance covariance matrix Ω_ϵ is normalized to I. In order to ensure that shocks ϵ_t are truly structural and different from the reduced form residuals e_t, they must be orthogonalized. The orthogonalization process ensures that structural shocks are mutually uncorrelated with each other. The co-variance matrix is assumed to be an identity matrix, containing zero elements off the diagonal and implying that the structural shocks are uncorrelated.

Consequently, ϵ_t can be accorded an economic interpretation. SVARs are popularly used to identify or pin down shocks and to examine the effects of structural innovations on dependent variables in the original model. The SVAR model is used to relate the observable residuals of the classical VAR to the unobserved innovations in the structural forms. It provides the nexus between data and theory. The SVAR methodology, with the aid of the impulse response functions, forecast error variance decomposition and historical variance decomposition, can be employed to identify shocks and trace out how shocks are propagated. The representation of a structural model is often based on some relationship anchored on economic theory or prior beliefs. Following Kilian (2013), who observe that the reduced form errors (e_t) are generally a weighted average of the structural shocks (ϵ_t) and Bjornland & Thorsrud, 2015 who consider reduced form errors (e_t) as a linear combination of structural shocks (ϵ_t), any effort at studying the response of the vector y_t to the reduced form errors e_t will not provide us with information about the response of y_t to the structural shocks, ϵ_t. All the parameters of the reduced form model can be estimated by ordinary least squares (OLS) method, equation by equation and the co-variance matrix Ω_e can be computed as well.

In the case of equation 2.2, the model is not identified. To achieve identification, the equation can be multiplied by the inverse of the contemporaneous impact matrix B_0 (i.e B_0^{-1}), as follows:

$$B_0^{-1}B_0y_t = B_0^{-1}B_iy_{t-i} + B_0^{-1}\epsilon_t \tag{2.3}$$

This yields equation 2.4:

$$y_t \quad = \quad B_0^{-1}B_iy_{t-i} + B_0^{-1}\epsilon_t \tag{2.4}$$

Equation 2.4 is equivalent to the reduced form VAR expression in 2.1, where $A_i = B_0^{-1}B_{i,} \qquad i = 1, ..., p,$

$$e_t = B_0^{-1}\epsilon_t, \text{ and,}$$

$$Cov(e_t) = \Omega_e$$

The variance of the reduced form errors e_t can be stated as:

$$E(e_t e_t') = B_0^{-1}E(\epsilon_t \epsilon_t')B_0^{-1'} \tag{2.5}$$

This can be equivalently written as:

$$\Omega_e = B_0^{-1}\Omega_\epsilon B_0^{-1'} = B_0^{-1}IB_0^{-1'} = B_0^{-1}B_0^{-1'} \tag{2.6}$$

Equation 2.6 can be utilized to derive the unknown parameter elements in B_0^{-1}. In solving $\Omega_e = B_0^{-1}B_0^{-1'}$ we are confronted with a number of unknown parameters in the structural VAR, higher than the number of known parameters from the reduced form equation. The condition provided for solving for B_0^{-1} is that the number of unknown parameters in B_0^{-1} must not exceed the number of equations in the system. A violation of this rule will give rise to the problem of under-identification, which can be resolved by imposing extra identifying restrictions; that may be achieved through exclusion restrictions, proportionality restrictions or other equality restrictions (Kilian, 2013).

A popular approach is to get the required restrictions by making some elements of B_0^{-1} equal to zero, otherwise known as exclusion restrictions. Thus, some variables will not be allowed to impact other variables contemporaneously (Lütkepohl, 2013). If the number of free parameters in Ω_e is given as $N(N+1)/2$, the minimum number of restricted parameters in B_0^{-1}that would yield a unique identification is $N(N+1)/2$ (Kilian, 2013). The reduced form parameters depend on properties of the data therefore, any effort to determine structural parameters from properties of the data will result to indeterminacy unless an appropriate identifying restrictions can be found (Bjornland & Thorsrud, 2015).

2.4.2 Zero Short-run Restrictions

Zero Short-run Restrictions is based on the Cholesky decomposition which assumes a recursive structure. Shocks are identified by assigning one(s) to all elements in the main diagonal and zero(s) to all elements in the upper triangular matrix. The matrix B_0^{-1} is orthogonalized and can be matched to the error co-variance matrix through Ω_e. The Cholesky decomposition technique can be used to impose short run restrictions, which identify the structural shocks by ordering the variables in the system in a way that ensures the most exogenous variables comes first. This ordering procedure is often useful for constraining the response of specific variables in the immediate period sequel to an innovation (shock). In this way, structural shocks ϵ_t can be used to recover the lower triangular matrix which ensures that all parameters are exactly identified.

Despite its usefulness, the recursive procedure is flawed due to the specific rigidity of Cholesky orthogonalization shock identification scheme (Popescu, 2014). In addition, Kilian (2013) maintains that the orthogonalization of the reduced-form residuals through the application Cholesky decomposition procedure is appropriate only if there are economic justification for a recursive structure, otherwise, the exercise will produce a mere mechanical solution without theoretical content. Sims (1980), Bernanke & Blinder (1992) and Christiano *et al.* (1999) are three examples of the popular pioneering applications of the recursive identification scheme used for modelling monetary policy transmission mechanism.

2.4.3 Zero Long-run Restrictions

Alternatively, if long run set of restrictions is imposed on a VAR system, the impulse responses are constrained to reflect values consistent with economic rationale. In this case, the accumulated response of a particular variable to a shock are made to add to zero over the whole period of analysis. For instance, Blanchard & Quah (1989) in a bi-variate VAR model of output growth and the unemployment rate, assume that the long-run effect of a demand shock on growth in output is zero. Although, long run restrictions have been hailed for their close affinity with economic theory, they are however, said to, suffer from distortions arising from small sample biases and measurement errors (Peersman, 2005). In essence, the literature prove that it would be hard to accurately estimate the impulse response functions at long (infinite) horizons from a limited data span (Faust & Leeper, 1997). If a non-recursive identification scheme is followed, the rigidity of the Cholesky decomposition is avoided and one is able to freely impose restrictions in line with theoretical underpinnings. Here, there is greater flexibility to infuse a sufficient dose of economic theory on the model and the opportunity to reflect a more accurate description of the inter-dependencies among variables. However, this approach too has been criticized because of differences in identifying restrictions.

2.4.4 Sign Restrictions

The idea of the sign restriction procedure as an alternative methodology for identifying structural VAR is credited to the pioneering works of Faust (1998), Canova & De Nicolo (2002) and Uhlig (2005). They achieve identification by restricting the sign (and/or shape) of structural responses. There is no need to impose zero restrictions on the contemporaneous impact matrix as is required in SVAR. The system is set up to identify a set of impulse responses which agrees with theory-based sign expectations. Unlike the recursive and non-recursive methods of identifying VARs which are subject to criticisms largely due to the scepticism about the validity of the identifying restrictions employed in them, the sign restricted SVAR has a strong theoretical focus, given that applicable a priori expectations are usually extracted from the outputs of relevant dynamic stochastic general equilibrium (DSGE) model(s).

Restrictions are set on the sign of the impulse response, to condition its direction over a given horizon in response to specific alternative innovations (Jaaskela & Smith, 2011). Fry & Pagan (2011) argue that the sign restriction identification procedure is especially crucial in circumstances where variables are simultaneously determined because of bi-directional causality, thus making it difficult to employ any other alternative identifying restrictions. With sign restrictions, identification restrictions are validated by theoretical (DSGE) models. In addition, the common incidence of puzzles[9] in the macroeconomic literature raise the suspicion that, shocks identified in previous studies may not have been truly exogenous, therefore, addressing the puzzles require the imposition of proper signs on impulse responses[10] (Kim, 2013). Identification in models restricted using signs require that each shock is associated with a unique sign pattern. The use of sign restrictions VAR models have become commonplace in mainstream empirical macroeconomics. For instance, Canova (2007), Mountford & Uhlig (2009) and Pappa (2009) applied it to analyse fiscal shocks, Dedola & Neri (2007) used it to study the effects of technology shocks, Canova & De Nicolo (2002), Scholl & Uhlig (2008) for open economy shocks and Kilian & Murphy (2012), Baumeister & Peersman (2013) considered oil markets applications, while Fujita (2011) modelled labour market dynamics with it.

One main drawback of the sign restricted SVAR is that it does not imply unique identification as there may be many impulse responses that satisfy the specific sign restriction imposed. Fry & Pagan (2011) emphasize that it is almost impossible to find the exact identification when a set of impulse responses are compatible with a particular restriction, while Kilian (2013) also submit that, in the case of sign restriction, there is not a unique point estimate of the structural impulse response functions, and that sign identified VAR models are only set identified. This is as a

[9] e.g. liquidity puzzle, price puzzle, etc.

[10] The conditional correlation structure

result of the nature of sign restrictions, which are essentially regarded as inequality restrictions. Consequently, the task of identifying a particular impulse response, from the many, that truly summarizes the needed information in an efficient way is one that must be resolved.

2.4.5 Procedure for implementing Sign restriction

Given a set of sign restrictions, construction of structural impulse response functions require that we estimate the NxN matrix B_0^{-1} as found in e_t $=B_0^{-1}\epsilon_t$ from (3). Suppose we let P be the lower triangular Cholesky decomposition which satisfies the condition $\Omega_e = PP'$. Then $B_0^{-1} = PD$ and satisfies the condition $\Omega_e = B_0^{-1}B_0^{-1\prime}$for any orthogonal NxN matrix D. As opposed to P (a lower triangular Cholesky decomposition), PD is generally non-recursive. If we conduct repeated random samples or draws from the set $\mathbf{D}$ of orthogonal matrices D, a large range of probable solutions B_0^{-1}can be obtained. In line with Fernandez-Villaverde & Rubio-Ramirez (2010) in Kilian (2013), a set of admissible models can be constructed by taking draws from the set $\mathbf{D}$ and dropping candidate solutions for B_0^{-1} that are not in line with a set of a priori sign restrictions on the implied impulse responses functions.[11] Sariola (2015) summarized the steps involved in this procedure as follows: (i) Draw a NxN matrix L of $NID(0,1)$[12] random variables. Derive the QR decomposition of L such that $L = Q \cdot R$ and $QQ' = I_N$. (ii) Let $\mathbf{D} = \mathbf{Q}'$. Compute impulse responses using the orthogonalization $\mathbf{B_0^{-1}} = \mathbf{PD}$. If all implied impulse response functions satisfy the identifying restrictions, retain $\mathbf{D}$; otherwise, discard. (iii) Repeat the first two steps for a large number of times, recording each $\mathbf{D}$ that satisfies the restrictions (and the corresponding impulse response functions). (iv) Finally, choose the model which represents the median impulse responses. The impulse matrix $\mathbf{B_0^{-1}}$ that gives the median impulse responses could be interpreted as that which produces typical responses to the identified structural shocks, given that no unique $\mathbf{B_0^{-1}}$ exists. The proportion of the early set of candidate models that are in sync with the identifying restriction may be viewed, according to Kilian (2013) as an indicator of how informative the identifying restrictions are about the structural parameters.

[11] This section draws significantly from Fry & Pagan (2011), Kilian (2013),

[12] This is a random process, assumed to be normally and independently distributed

2.5 Model, Data and Estimation

In the spirit of Liu (2010) and Jaaskela & Smith (2011), we assume a small open economy, a feature that corresponds with the Nigerian economy. Consequently, a block recursive structure is imposed on the VAR model. The identified external shocks exert influence on the evolution of both foreign and domestic variables. In essence, to reflect the small open economy block structure, equation 2.4 above is re-written such that vector y_t is constructed as follows:

$$\begin{bmatrix} f_t \\ d_t \end{bmatrix} = \alpha x_t + \sum_{i=1}^{p} A_i \begin{bmatrix} f_{t-i} \\ d_{t-i} \end{bmatrix} + B_0^{-1} \begin{bmatrix} \epsilon_t^f \\ \epsilon_t^d \end{bmatrix} \tag{2.7}$$

[13] Where $y_t = \begin{bmatrix} f_t \\ d_t \end{bmatrix}$; f_t and d_t represent the vectors of foreign and domestic variables, respectively; x_t is the vector of exogenous variables and B_0^{-1} is the impact matrix of contemporaneous effects of the mutually uncorrelated foreign and domestic shocks vectors in the system. The modelling framework for the small open economy assumption requires that matrix A_i is the lower triangular matrix which does not allow the lagged values of domestic variables to affect those in the foreign block. The B_0^{-1} matrix also, in line with Karagedikli & Price (2012) would be restricted to a lower triangular matrix in order to capture the open economy features in the contemporaneous period.

$$\begin{bmatrix} \triangle y_t^w \\ i_t^{us} \\ \triangle o_t^p \\ i_t^d \\ \triangle y_t^d \\ \pi_t^d \\ \triangle \kappa_t \end{bmatrix} = A_1 \begin{bmatrix} \triangle y_{t-1}^w \\ i_{t-1}^{us} \\ \triangle o_{t-1}^p \\ i_{t-1}^d \\ \triangle y_{t-1}^d \\ \pi_{t-1}^d \\ \triangle \kappa_{t-1} \end{bmatrix} + A_2 \begin{bmatrix} \triangle y_{t-2}^w \\ i_{t-2}^{us} \\ \triangle o_{t-2}^p \\ i_{t-2}^d \\ \triangle y_{t-2}^d \\ \pi_{t-2}^d \\ \triangle \kappa_{t-2} \end{bmatrix} + B_0^{-1} \begin{bmatrix} \epsilon_t^{\triangle y^w} \\ \epsilon_t^{i^{us}} \\ \epsilon_t^{\triangle o^p} \\ \epsilon_t^{i^d} \\ \epsilon_t^{\triangle y^d} \\ \epsilon_t^{\pi^d} \\ \epsilon_t^{\triangle \kappa} \end{bmatrix} \tag{2.8}$$

A small open economy structural VAR model suitable for Nigeria and other similar SOEs can be summarized as shown in 2.8 above, where all three (3) foreign and four (4) domestic variables and shocks have been represented assuming a lag order of 2. Sign restrictions can be imposed on the shock matrix $B_0^{-1}$to identify the model. The selection of model variables reflect the tradition in the literature[14] which often accord important roles to global demand, US monetary policy stance and commodity prices in shaping macroeconomic trends in the home fronts of small

[13] Recall that $A_i = B_0^{-1} B_i$, and $B_0^{-1} = B_0$.

[14] Please see Canova (2005); Jaaskela & Smith (2011); Silva (2012)

open economies. Fluctuations in inflation, output, interest rate and terms of trade dynamics, among others, are often used to approximate business cycle evolution.

$$f_t = \begin{bmatrix} \triangle y_t^w & i_t^{us} & \triangle o_t^p \end{bmatrix}' \tag{2.9}$$

$$d_t = \begin{bmatrix} i_t^d & \triangle y_t^d & \pi_t^d & \triangle \kappa_t \end{bmatrix}' \tag{2.10}$$

The foreign block (f_t) includes the growth rate of world output ($\triangle y_t^w$), the US federal funds rate (i_t^{us}) and changes in the oil price ($\triangle o_t^p$), while the domestic block (d_t) includes the domestic interest rate (i_t^d), the growth rate of domestic output ($\triangle y_t^d$), the domestic inflation rate (π_t^d) and changes in the terms of trade ($\triangle \kappa_t$). In this set up, f_t is block exogenous to d_t such that domestic variables and shocks ϵ_t^d do not affect foreign variables in f_t, while foreign shocks in ϵ_t^f are assumed to affect variables in both f_t and d_t; and f_t are determined by its own lags and foreign shocks.

With reference to Nigeria, oil price shocks are largely exogenous, given that factors determining the evolution of crude oil price are predominantly international. The US monetary policy innovations has effects on developments in the Nigerian financial market due to the effects of globalization and trade flows. In the same vein, the state of the global economy may exert considerable influence on Nigeria's economy given her status as a net exporter of oil and a net importer of capital and consumer goods. The vector of foreign and domestic shocks for Nigeria is shown as follows:

$$\epsilon_t^f = \begin{bmatrix} \epsilon_t^{\triangle y^w} & \epsilon_t^{i^{us}} & \epsilon_t^{\triangle o^p} \end{bmatrix}' \tag{2.11}$$

$$\epsilon_t^d = \begin{bmatrix} \epsilon_t^{i^d} & \epsilon_t^{\triangle y^d} & \epsilon_t^{\pi^d} & \epsilon_t^{\triangle \kappa} \end{bmatrix}' \tag{2.12}$$

In the foreign block of structural innovations (ϵ_t^f), $\epsilon_t^{\triangle y^w}$ is the global demand shock, which represents any surprise event that increases world demand; $\epsilon_t^{i^{us}}$ is the US monetary policy shock, which is an indicator of US contractionary monetary shock while $\epsilon_t^{\triangle o^p}$ is the oil price shock, which is embedded in those phenomenon that moves oil price changes in the upward direction. In the domestic shocks block (ϵ_t^d), $\epsilon_t^{i^d}$ is the domestic monetary policy shock, conceived as any factor that moves domestic interest rate upward. The interest rate is the main instrument of monetary policy used by the central bank to achieve set macroeconomic objectives. $\epsilon_t^{\triangle y^d}$ is the domestic demand shock, which elicits a positive change in domestic output growth rate, $\epsilon_t^{\pi^d}$ is the supply shock, which cuts aggregate supply due to cost-push inflation; while $\epsilon_t^{\triangle \kappa}$ represents the country trade shock, which causes an increase to changes in the terms of trade.

2.5.1 Identification Scheme

In the literature, the identification of structural vector auto-regressive models with sign restrictions often follow robust conditional types of restrictions involving the sign of the responses of certain variables to shocks (Canova, 2005). Sign restrictions applied to identify shocks are usually by-products of DSGE models and/or intuitions gleaned from economic theory (Sariola, 2015). For instance, Peersman & Straub (2004) utilize sign restrictions derived from two DSGE models; a sticky price model and a real business cycle model, to examine the effects of monetary policy, labour supply, technology and aggregate spending shocks on hours worked for the economy of the Euro Zone. In a small open economy application, Liu (2010), following Gali & Monacelli (2005) estimates a stylized small open economy DSGE model through simulation to derive a set of restrictions applied to a VAR analysis. In the case of Sariola (2015), sign restrictions derived from relevant DSGE models were employed to achieve identification. Specifically, it combined sign restrictions implied by the Riksbank's Ramses II (Adolfson & Walentin, 2013 and Peersman & Straub, 2004) to uniquely identify four shocks for the Swedish economy.

In this study, we assign restrictions to identify specific external shocks based on direct intuitions established from a suite of relevant small open economy DSGE models, developed to capture the peculiar structure of two main oil exporting African economies, namely Nigeria and Algeria. In the case of Nigeria, Olayeni (2009a) through an estimated small open economy DSGE-BVAR model reported that a one-time monetary policy shock elicit negative response in both inflation and output growth; while it led to a rise in interest rate and a less-discernible appreciation in the exchange rate. The terms of trade shock impacted on these variables in a similar manner. Adebiyi & Mordi (2012) estimated a new Keynesian DSGE model for the Central Bank of Nigeria (CBN), and found that an oil price shock lowered inflation, widened the output gap, reduced the maximum lending rate, caused depreciation in the nominal exchange rate and raised government expenditure in the periods immediate to the innovation. A shock to the nominal exchange rate (meaning a depreciation) at first increases the output gap and reduces it in subsequent periods; while the shock caused increases in the maximum lending rate, the general price level and in fiscal spending. In Allegret & Benkhodja (2015), a DSGE model for the oil exporting African country of Algeria was estimated using the Bayesian techniques and increases in output and inflation were observed following an oil price shock.

Based on these results, sign restrictions are applied as shown in table 2.5.1 below. We identified three external shocks, namely: global demand shock ($\epsilon_t^{\triangle y^w}$), US monetary policy shock (i_t^{us}) and oil price shock ($\triangle o_t^p$). The shocks are propagated through both foreign and domestic variables. In the table, a positive sign (+) indicates that the response of a variable to a shock is restricted to be positive, whereas, a negative sign (-) means that the response of a variable to a shock is set to negative. The symbol (?) indicate no restrictions are imposed and that we are agnostic about the particular sign that a variable will assume in response to a given shock. Our purpose is to uncover how external shocks impact the domestic business cycle and the relative importance of each foreign shock. Consequently, we do not identify domestic shocks.

Identification Scheme based on Sign Restrictions								
Shocks/Variables[15]		GOG	FFR	OPG	DIR	DOG	DINF	TOT
External Shocks	GDS	(+)	(+)	(+)	(+)	(+)	(+)	(+)
	USMPS	(-)	(+)	(?)	(+)	(-)	(?)	(?)
	OPS	(-)	(-)	(+)	(+)	(+)	(?)	(+)

Table 2.4: Identification Scheme based on Sign Restrictions

A positive global demand shock is assumed to elicit an increase in all global and domestic macroeconomic aggregates (Mumtaz & Surico, 2009). Shock to the US monetary policy is expected to propel a rise in the US federal funds rate and in the domestic interest rate. An emerging market economy typically responds to a US monetary policy shock with an increase in the monetary policy rate in favour of international competitiveness required to sustain or attract capital flows into the country. We are however agnostic about how oil price, domestic inflation and terms of trade responds to a U.S. monetary policy shock. Oil price shock is believed to impact negatively on both global output growth and the Federal funds rate. This is in line with Carlstrom & Fuerst (2006), Kilian & Lewis (2011) and Inoue & Kilian (2013) who argue that oil price shock causes increase in the price of oil and induces global real activity to fall on impact.

Bernanke *et al.* (1997a) submits that the Fed responds to oil price shocks with restrictive monetary policy in order to check inflation. Kilian & Lewis (2011), however, questioned this proposition on three main grounds. First, they argue that the Fed cares as much about output and employment stabilization as it cares about containing inflation; and that the Fed was overtly concerned with the output objective during the 1970s. Second, given that the demand side of oil price shock transmission channel (which may be further complicated by higher precautionary savings) is stronger than the cost-induced supply side channel, an exogenous oil price shock will be recessionary or deflationary and thus, there is no basis to pursue a restrictive monetary policy in response to oil price shock. Third, oil price shocks are considered as symptoms of a cause, which demands that policy responses target the underlying

[15] GDS, USMPS and OPS are Global Demand, US Monetary Policy and Oil Price Shocks, respectively. See list of acronyms.

demand and supply shocks that drive oil price. The effect an oil price shock would have on the economy depends on the source of the shock (Kilian, 2008). For instance, if an oil price shock is demand driven, it may not result in decline in output after all. The argument by Kilian & Lewis (2011) corroborate findings by Hamilton & Herrera (2004), which show that Bernanke *et al.* (1997a)'s conclusion about the Fed's restrictive monetary policy response to oil price shock was mainly influenced by the small lag length applied in their model. Therefore, using a larger sample and higher lag length to capture the dynamics in the monthly data, they found that monetary policy in the US was actually loose in response to oil price shocks.

Based on Allegret & Benkhodja (2015), domestic output growth responds positively to oil price shocks. Although, our reference theoretical model suggest a positive inflation response to oil price innovations, we chose to remain agnostic about this interaction. Oil price shock and domestic interest rate are observed to be positively correlated in keeping with the restrictive monetary policy stance targeting inflationary pressures due to oil boom in the economy.

$$\begin{bmatrix} e_t^{\triangle y^w} \\ e_t^{i^{us}} \\ e_t^{\triangle o^p} \\ e_t^{i^d} \\ e_t^{\triangle y^d} \\ e_t^{\pi^d} \\ e_t^{\triangle \kappa} \end{bmatrix} = \begin{bmatrix} + & - & - & 0 & 0 & 0 & 0 \\ + & + & - & 0 & 0 & 0 & 0 \\ + & ? & + & 0 & 0 & 0 & 0 \\ + & + & + & 0 & 0 & 0 & 0 \\ + & - & + & 0 & 0 & 0 & 0 \\ + & ? & ? & 0 & 0 & 0 & 0 \\ + & ? & + & 0 & 0 & 0 & 0 \end{bmatrix} * \begin{bmatrix} \epsilon_t^{Global\ Demand} \\ \epsilon_t^{US\ Monetary\ Policy} \\ \epsilon_t^{Oil\ Price} \\ \epsilon_t^{Domestic\ Monetary\ Policy} \\ \epsilon_t^{Domestic\ Demand} \\ \epsilon_t^{Domestic\ Supply} \\ \epsilon_t^{Trade} \end{bmatrix} \quad (2.13)$$

As shown in 2.13, the sub-block of domestic shocks is inactive, indicating that domestic shocks are not allowed to impact the system of equations for foreign and domestic variables. Only foreign shocks are activated and they impact all the equations or variables in the system.

2.5.2 Data and Estimation Procedure

To estimate the specified SVAR model, we apply the Bayesian technique on a seven-variable quarterly dataset over the period 1982Q1 - 2016Q1 for the full sample estimation and the period 1982Q2 - 2007Q4 for the sub sample estimation robustness exercise performed to see if the recent global financial crisis changes our results significantly. All data series are in elasticity forms, thus, making it possible to compare results associated with different variables more credibly. Our external block variables include: global output growth rate, US federal funds rate and oil price. These variables are important in our model set up, as they summarize the main characteristics of the international business cycle dynamics which have implications for the global economy. The domestic block contain domestic indicator variables for the business cycle fluctuations. They include output growth rate, inflation, interest rate and terms of trade. Data on global output growth and US federal funds rate are from World bank and the Fed data bases, respectively; while terms of trade data is from Alfred (St. Louis Fred). The growth rate of domestic output is sourced from the Nigerian National Bureau of Statistics (NBS), while oil price series, inflation and 3-month deposit interest rate are sourced from the Central Bank of Nigeria's Statistical Bulletin. Our diagnostic tests on the data show that the series do not have unit root, the VAR system is stable and the optimal lag length for model estimation is 2 based on four different information criteria.

The Bayesian technique is often preferred when the sample is short and the number of variables in the VAR system is relatively large. In a large VAR model with small sample, the likelihood function does not behave well. Also, there is a problem of over-fitting arising from over-parameterization, which tend to undermine the reliability of the estimates. However, in a Bayesian setting, prior information is used to compress models with huge coefficients on distant lags or explosive dynamics Silva (2012). In line with the steps laid out in 2.4.5, we employ a prior that assumes a Normal-Wishart structure for the parameters of the reduced form to generate a posterior of the same form, based on the identifying restrictions.

2.6 Presentation and Discussion of Results

2.6.1 External Shocks and Domestic Business Cycle: Baseline Model

Each of the shocks elicits a set of impulse responses contained within the dotted lines which indicates the upper and lower bands of the identified set, while the solid line is the median impulse response for each set. In the baseline model, we conducted estimation using full sample data covering the period 1982Q1 - 2016Q1. The data range include both pre- and post-financial crisis period. GOG is global output growth, FFR is US federal funds rate, OPG is oil price growth, DOG is domestic output growth, DINF is domestic inflation, TOT is terms of trade and DIR is domestic interest rate.

2.6.1.1 Global Demand Shock and Domestic Business Cycle

The effects of external shocks on the movement of key domestic business cycle variables can be inferred from the dynamic responses of the variables to external innovations. The degree of a variable's sensitivity to a shock is conveyed through the impulse response functions generated with the estimated model. As shown in figure 2.4, a unit shock to the global demand resulted in significant increase in the global output growth and the tightening of the US monetary policy. The stance of the US monetary policy tended to mirror the global momentum of growth as both increased slightly from the initial response and eventually returned to steady state after the twentieth quarter. This results suggest that the Fed considers the state of the global economy in its monetary policy decisions. Similarly, the global demand shock elicit a sharp increase in the oil price growth and a milder increase in the terms of trade. However, these responses were short-lived as oil price growth and changes in terms of trade waned barely after the second quarter and became fully dissipated by the seventh quarter. The result reflect the volatile nature of the oil price and the potential vulnerabilities inherent in relying on export of crude oil as a major revenue earner. Whereas, domestic inflation response to global demand shock is remarkably high, volatile and short-lived, domestic interest rate's response was initially aggressive, but later became moderate and persistent until the twenty-fifth quarter. Central banks in emerging economies often deploy monetary policy to achieve an intermediate objective of ensuring adequate foreign exchange liquidity in order to ward-off potential speculative attacks on the currency, which can trigger inflation. They often maintain a relatively high interest rate to attract capital flows in to the economy.

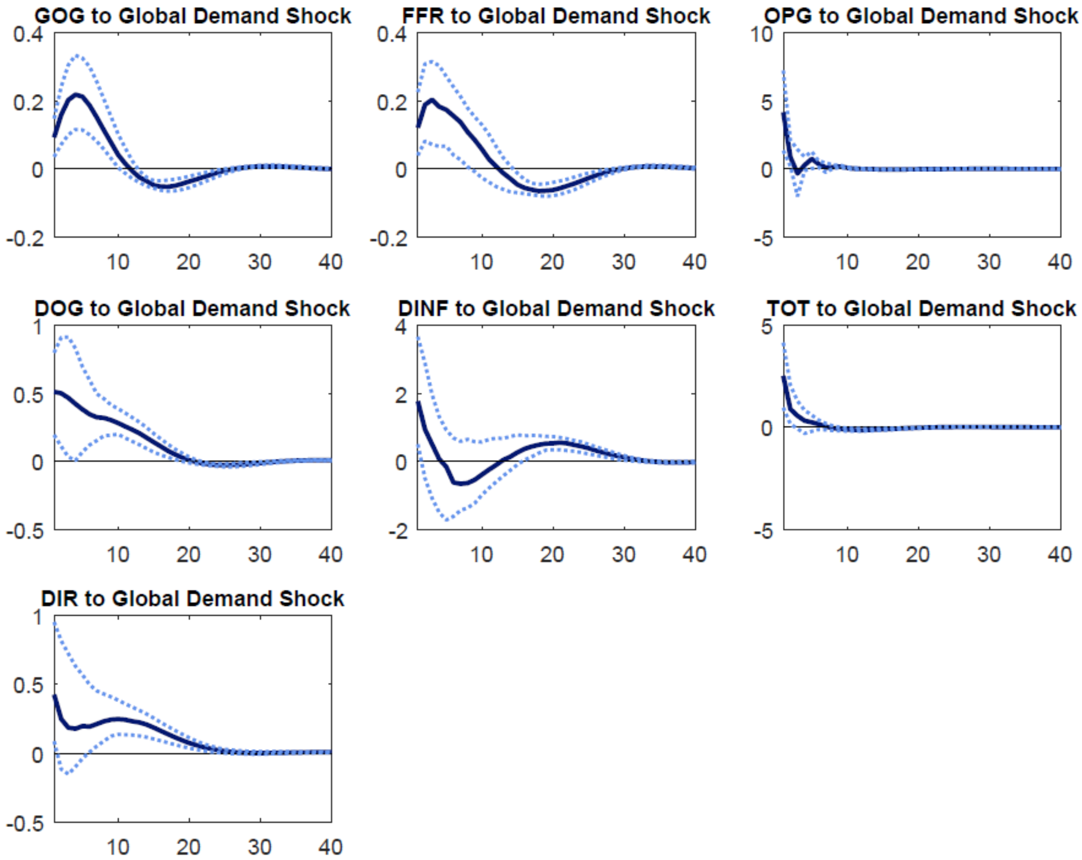

Figure 2.4: Impulse Response of Global Demand Shock

2.6.1.2 US Monetary Policy Shock and Domestic Business Cycle

The dampening effect of US monetary policy shock on the global output growth is fairly significant on impact. As seen in figure 2.5, the decline in the global output growth is most intense in the fourth quarter before returning to steady state in the fifteenth quarter. This response underscores the global counter-cyclical implication of tightening of monetary policy by the US, in order to reign in on the inflationary pressures associated with increased world-wide economic momentum. Given that we are agnostic about the response of oil price to a US monetary policy shock, the response is found to be positive, significant but unsteady as it jumped to negative territory in the third quarter and rebounded in the sixth quarter before returning to steady state in the eighth quarter. This oil price developments indicate the uncertainty surrounding the duration of the effect of the US monetary policy surprises on oil price growth. On impact, the US monetary policy shock had no effect on the terms of trade. The subdued impact became manifest and peaked near zero in the third quarter and then gradually dissipated into steady state by the eighth quarter. Domestic inflation's positive response to the US monetary policy shock happens after a quarter lag or delay. It peaks moderately in the fifth quarter before dissipating eventually in the thirteenth quarter.

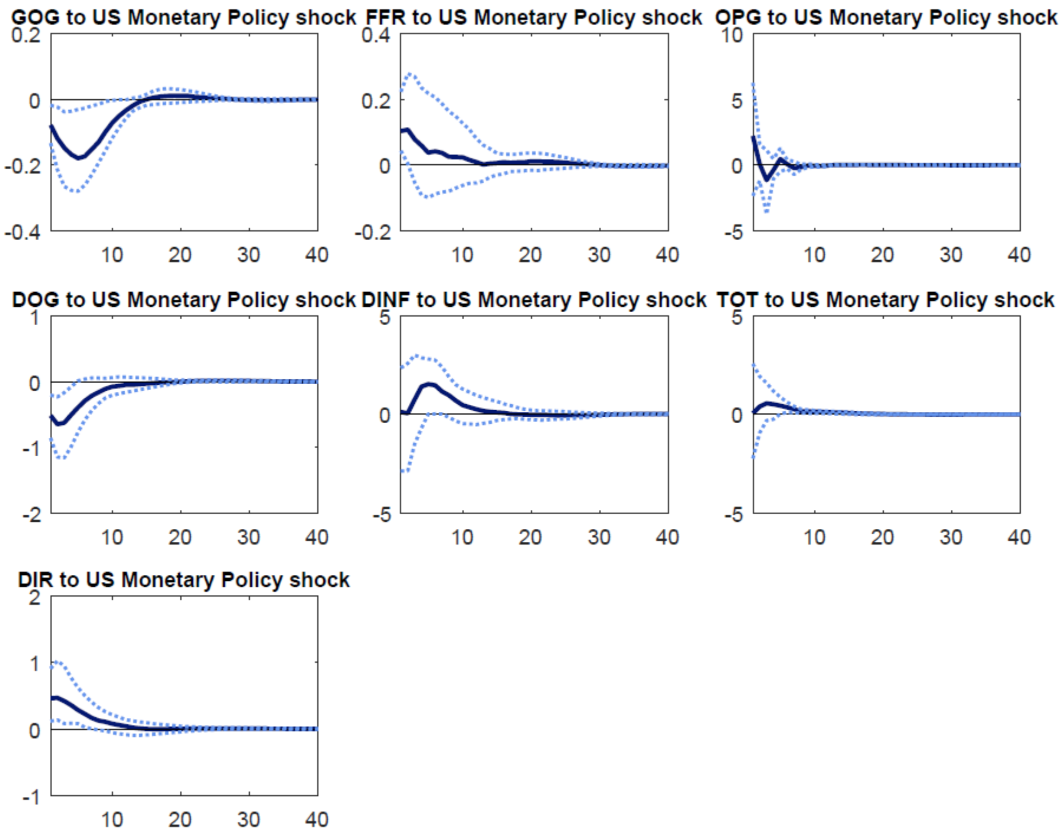

Figure 2.5: Impulse Response of the U.S. Monetary Policy Shock

A US monetary policy shock is a trigger for capital outflow from Nigeria. Substantial capital outflow in response to higher interest rate structure in the US can precipitate inflationary pressure in Nigeria via the exchange rate channel. The delay period observed in inflation's response to a US monetary policy shock may be attributable to investors possible cautious attitude or their inability to liquidate their current holdings immediately, owing to prevailing capital control measures. Domestic interest rate responded quite positively to the tightening of monetary policy in the US. This is a plausible response by any small open economy that needs to retain and attract capital inflows to support external reserves.

2.6.1.3 Oil Price Shock and Domestic Business Cycle

A major external shock that affect the world economy and particularly the oil exporting small open economies is oil price shock. Impulse response functions as shown in figure 2.6 indicate that one unit shock to oil price growth elicit considerable decline in global output growth. On the other hand, the response of the US monetary policy to a unit shock to oil price is rather aggressive and persistent. This is because, while global output growth declined by about 0.1 percent before reverting finally to steady state in the thirteenth quarter, the US monetary policy was eased by nearly 0.25 percent to accommodate the oil shock and it did not revert to steady state until around the thirteenth quarter. This results suggest that the US Fed tend to respond well and for a long time to developments in the global oil price. Oil price response to its own shock is sharp but short-lived, while terms of trade's response to oil price growth shock is positive, considerable and short; in the manner of oil price response to it's own shock. It seems evident from this dynamic interactions, that there is no guarantee that a positive oil price response to an oil shock can be sustained beyond three quarters as shown in figure 2.6.

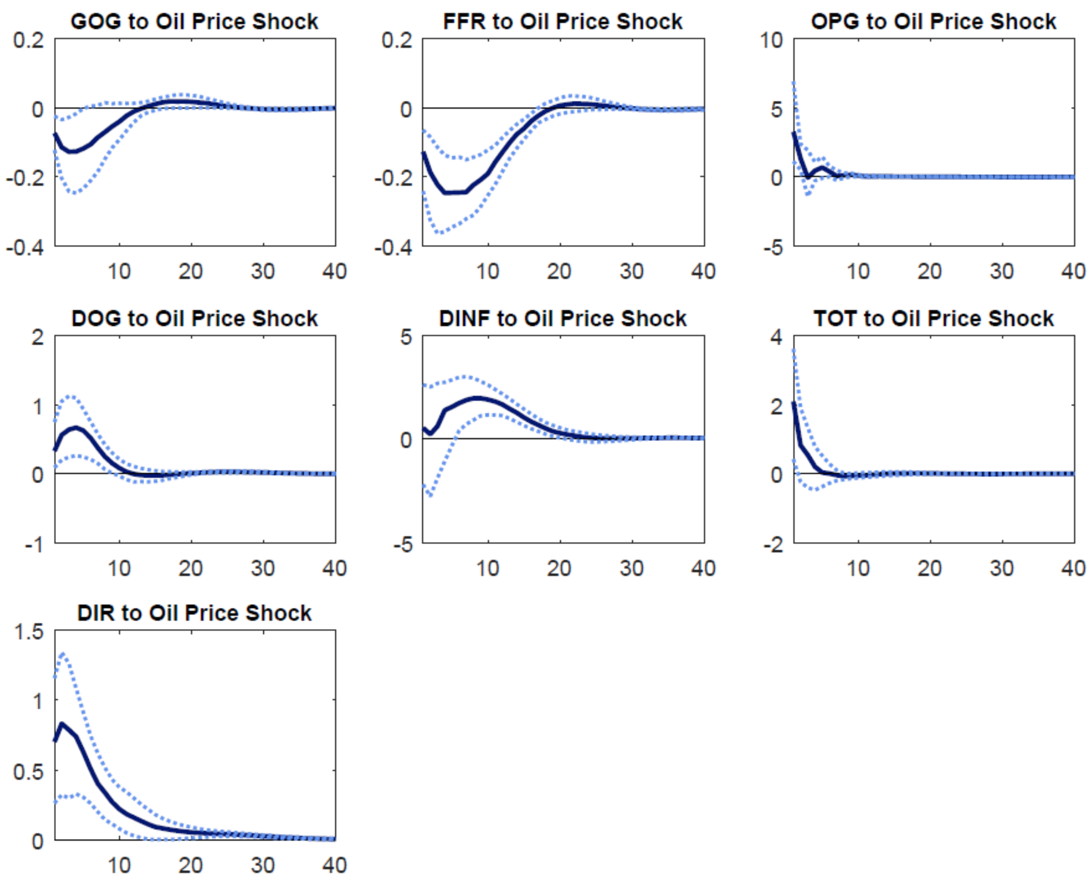

Figure 2.6: Impulse Response of Oil Price Shock

Domestic output growth, a major business cycle variable, show a mild but positive response to oil price growth shock and the response persisted for nearly 10 quarters. Domestic inflation's sluggish, positive and unsteady response to oil price shock grew to about 2 percent in the thirteenth quarter before dyeing out finally just after quarter 20. The initial low and unsteady inflationary response to oil price shock may be connected to the effect of increased oil revenue and subsequent rise in the external reserves which enhances the capacity of most oil exporting SOEs central banks to support or defend the domestic currency. However, when the currency comes under severe attack, the central bank is compelled to adjust the value of the currency either through outright devaluation or a managed float system of currency adjustment, thus, resulting to an inflation up-tick. Oil price shock also elicit a 0.7 percent tightening of the domestic monetary policy. It is common that in periods when oil price shock is prevalent, an oil exporting SOE central bank uses tight monetary policy to achieve a positive real interest rate environment and to address the threat of rising inflation in the economy.

2.6.2 External Shocks and and Domestic Business Cycle: A Robustness Check

Given the severity of the experience of the recent global financial crisis and the possible effects it may have had on the dynamic interactions among the variables in our model over the sample period 1982Q2 to 2016Q1, we conduct a simple robustness exercise by using a sample that excludes data points from the period of the global financial crisis till date. Policy responses by different governments and central banks to the crisis such as quantitative easing, the zero lower bound interest rate and the use of forward guidance may have effected the data, with implications for our earlier results. Consequently, we carry out the same estimation on data span of 1982Q1 - 2007Q4.

2.6.2.1 Global Demand Shock: Pre Crisis

On impact, global demand shock elicit a marginal response of 0.85 percent in global output growth. The shock has become more persistent and volatile given that its eventual return to steady state did not happen until quarter 30. When the effect of the global financial crisis is discounted, global output growth response to the global demand shock becomes less pronounced and more volatile, showing high persistence. Both oil price and terms of trade's response to the global demand shock became tighter and briefer, barely lasting till second quarter before dyeing out completely. Both the domestic output growth and domestic interest rate followed a similar pattern with results in the full sample size. Unlike the pronounced inflation volatility associated with the full sample estimation results, inflation volatility moderates in the current estimation results; suggesting that the global financial crisis contributes to high inflation volatility in Nigeria.

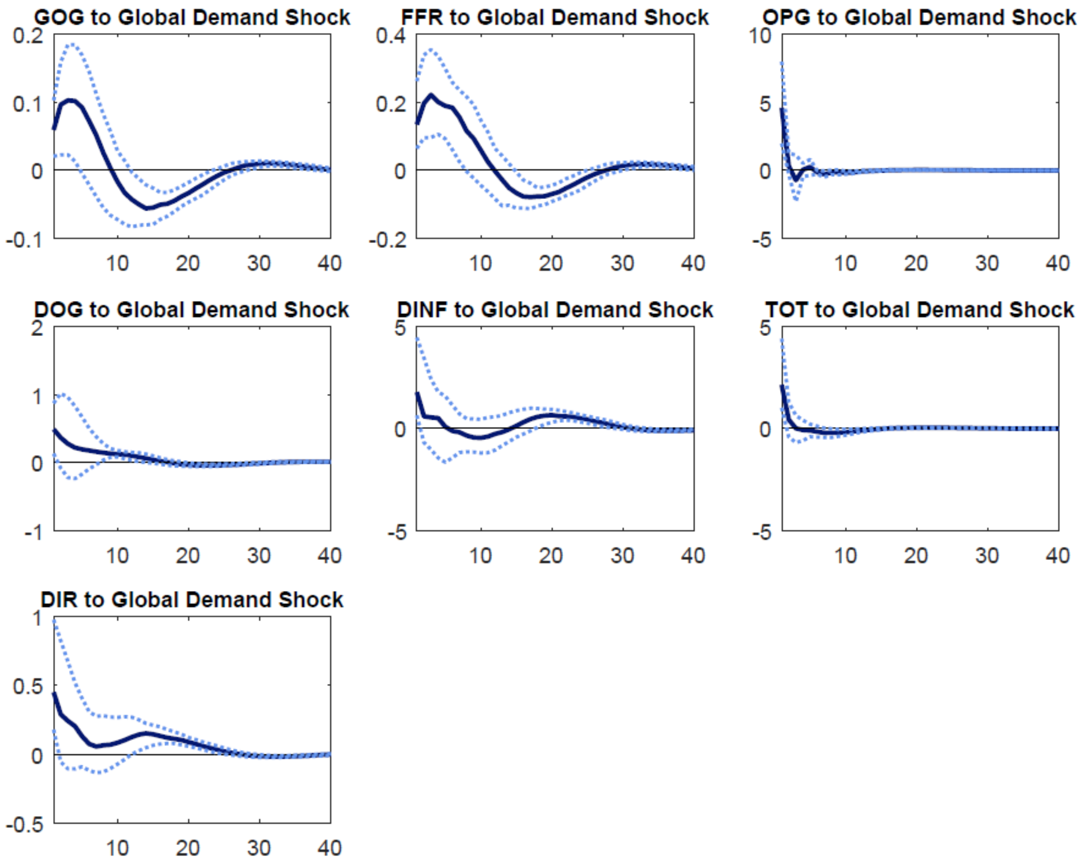

Figure 2.7: Impulse Response of the Global Demand Shock (Pre-GFC)

2.6.2.2 US Monetary Policy Shock: Pre Crisis

The US monetary policy shock reduced the global output growth rate by a fairly considerable margin. However, when compared to previous estimation reported in figure 2.6 the effect shown in figure 2.8 is not as strong, though it is more persistent. It appears, from this result, that the magnitude of the counter-cyclical effect of a US monetary policy shock will be slightly larger with shorter persistence in a world with financial crisis of the scale of that of 2008 than in a world without such a crisis. In this estimation, where we are also agnostic about the US Monetary policy shock - oil price growth interaction, it is found that oil price growth's response is positive but negligible and very short-lived. Similarly, the terms of trade's response to the shock is a subdued positive one which dies out by the tenth quarter. The domestic output growth shrank moderately and returned to steady state by the eighth quarter in response to a unit shock to the US monetary policy. The results show that on impact the US monetary policy shock caused a temporary fall in inflation, but by the third quarter, inflation had risen significantly and the trend remained persistent till the twenty-fifth quarter. Domestic interest rate's response to a US monetary policy shock is positive and similar in magnitude to that in the earlier estimation but different in terms of persistence level. The effect of the shock persists in the current estimation until the twentieth quarter compared to the previous estimation which dissipated quicker in the tenth quarter.

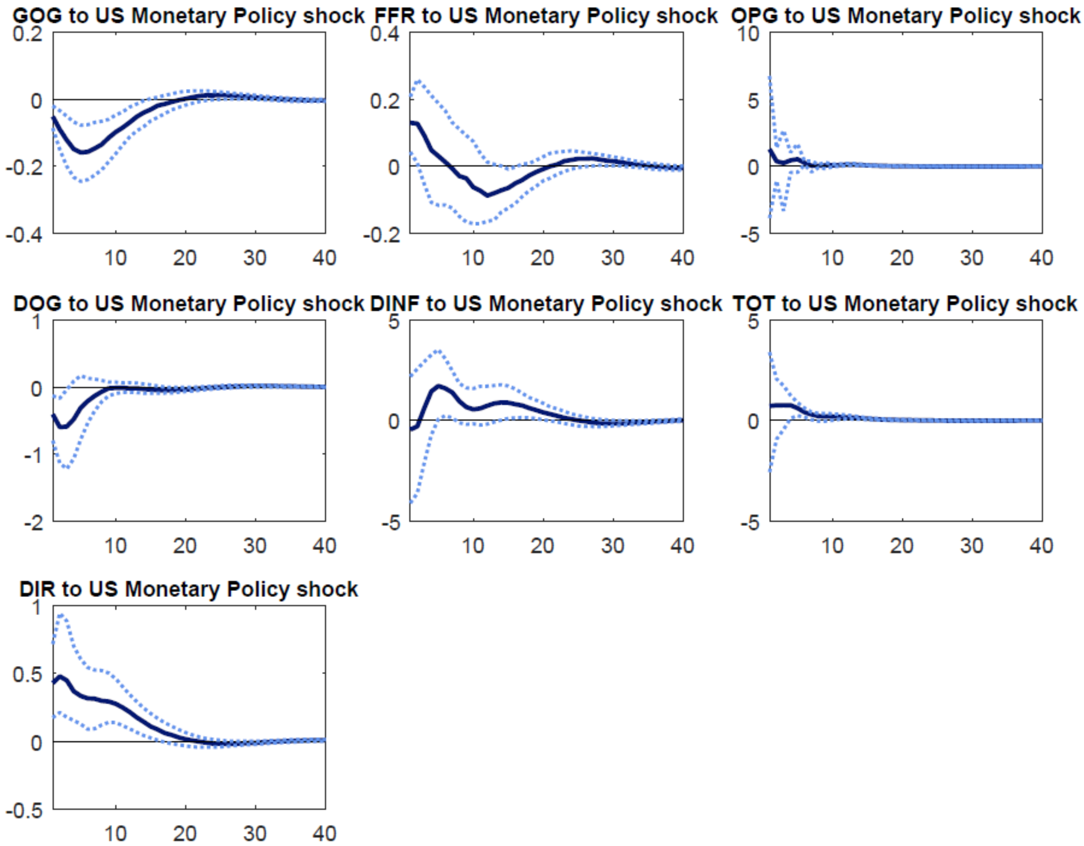

Figure 2.8: Impulse Response of US Monetary Policy Shock (Pre-GFC)

2.6.2.3 Oil Price Shock: Pre Crisis

Generally, the intensity of oil price shock's effects is similar in both estimations, however, varying degrees of persistence exist. Whereas, the impact of the shock is more persistent on global output growth, federal funds rate, domestic output growth and inflation in the pre-crisis model, the domestic interest rate response to oil price shock is more persistent in the model with full sample. Intensity and persistence of oil price shock are essentially the same in the both estimations for oil price and terms of trade. As shown in figure 2.9, domestic inflation, following an agnostic identification, exhibits a temporary negative response on impact before reversing to positive territory in the 3rd quarter. This initial negative inflation response to oil price shock is at variance with the small, volatile but positive response inflation exhibit in the full sample estimation. This result tend to suggest that the central bank is more keen on the effect of oil price shock on inflation when the global economy is exposed to a financial crisis.

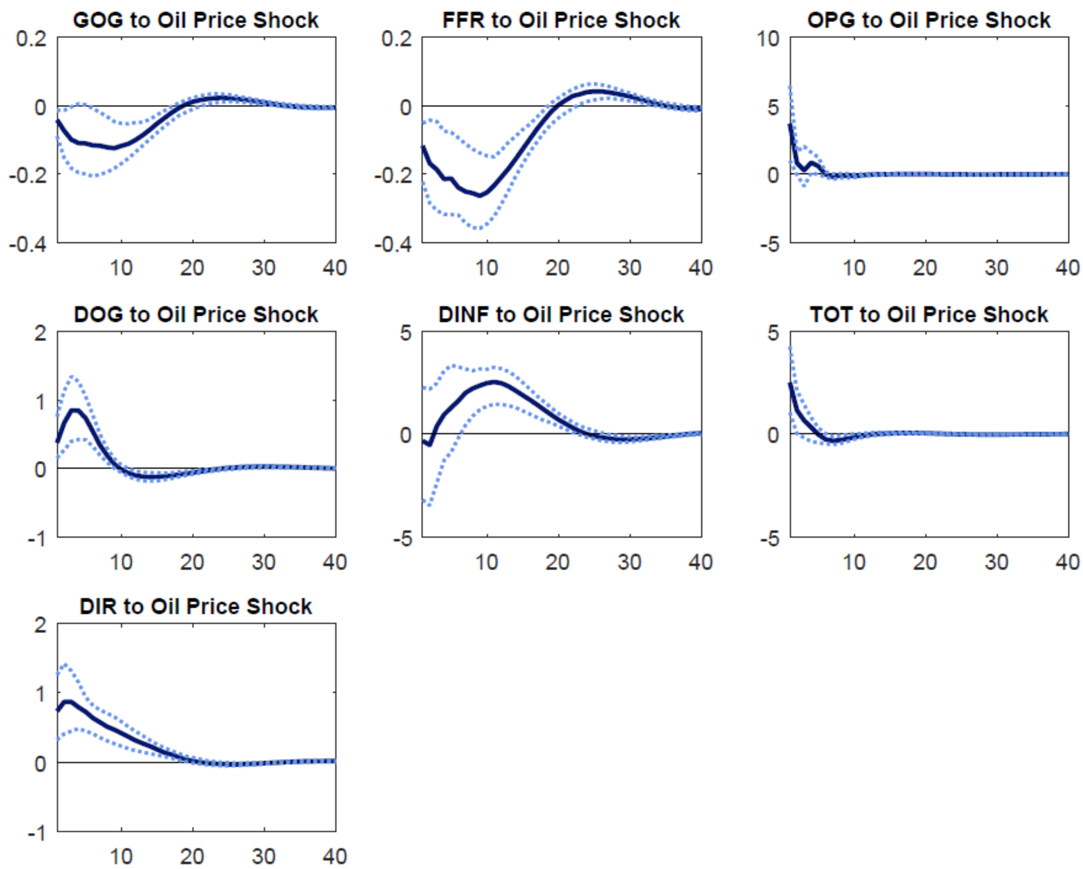

Figure 2.9: Oil Price Shock (Pre-GFC)

2.6.3 Historical Decomposition of External Shocks

2.6.3.1 External shocks Contributions to Foreign Business Cycle Fluctuations

The computed historical decomposition can provide strong insights about individual external shock's contributions to the evolution of each business cycle variables on an historical basis. In figures 2.10, 2.11 and 2.12 we show the contributions of the three identified external shocks to the global output growth, the US federal funds rate and the oil price growth over the entire sample period (1982Q2 - 2016Q1). The historical contributions of the decomposed shocks are displayed in the upper panels of each figure, while a trend chart of the underlining foreign variables that these shocks drive are plotted in the lower panels of the referenced figures. Figure 2.10 indicates that in our model, oil price and global demand shocks are the dominant drivers of the global output growth, while the US monetary policy shocks is also shown to play an important role as a co-driver of the changes in the global output. Three main episodes have been identified in the sample; two of which represent the worst dips in global output growth and one, the best episode of growth in the world economy during the period in focus. The first episode of significant deceleration in world growth took place in the period 1991 - 1994, during which negative oil price shock and US monetary policy shock held sway, respectively as key contributing drivers of the global business cycle fluctuation.

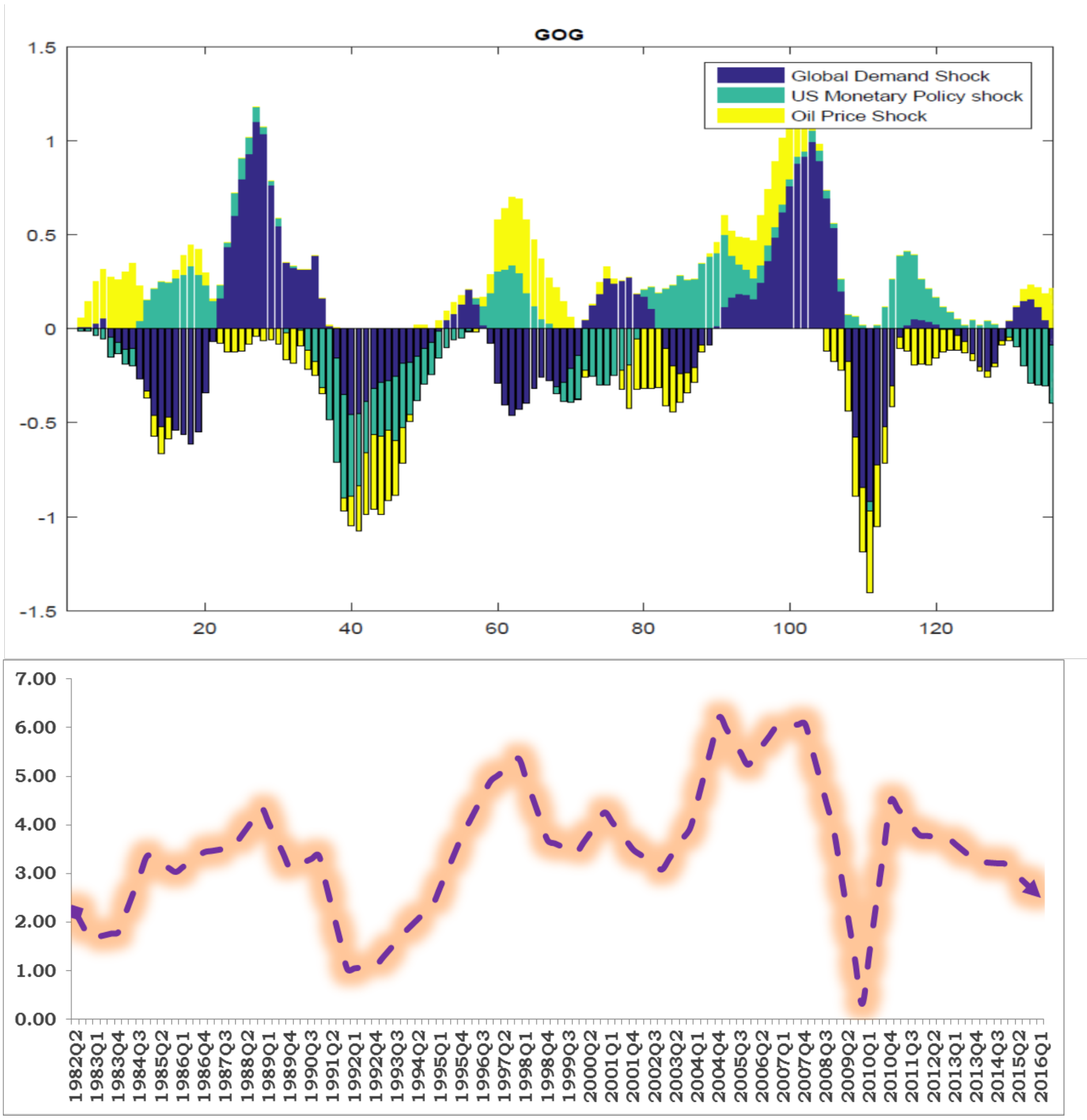

Figure 2.10: Historical Decomposition of Global Output Growth and it's trend

On the other hand, during the biggest recessive episode in 2008, negative oil price shock featured in our model as a dominant contributor to global output growth ahead of the negative demand shock, with the US monetary policy shock playing a rather muted role. However, our model does not fully account for the 2008/09 global financial crisis episode, given that the crisis originated from financial fragilities inherent in major world economies. The crisis was caused and amplified by financial frictions such as risk shock, equity shock, credit shock, etc. (Christiano *et al.*, 2014); rather than by shocks featured in this model.

During the main global output growth episode linked to 2004 - 2007, oil price shock is seen as the principal contributor to world economic growth while the US monetary policy and global demand shocks ran neck-to-neck as second and third contributors to global output growth in our model. A positive global demand shock is associated with rising momentum in the global economy and negative global demand shocks with world economic recessive tendencies. Similarly, for the most part of our model's sample, positive oil price shocks are associated with higher growth outcomes while negative oil price shocks are characterized by lower growth outcomes. The US monetary policy shock is the most counter-cyclical innovation in this historical context. This means that the US monetary policy stance tends to be loose during global economic slow downs and restrictive when growth momentum is high.

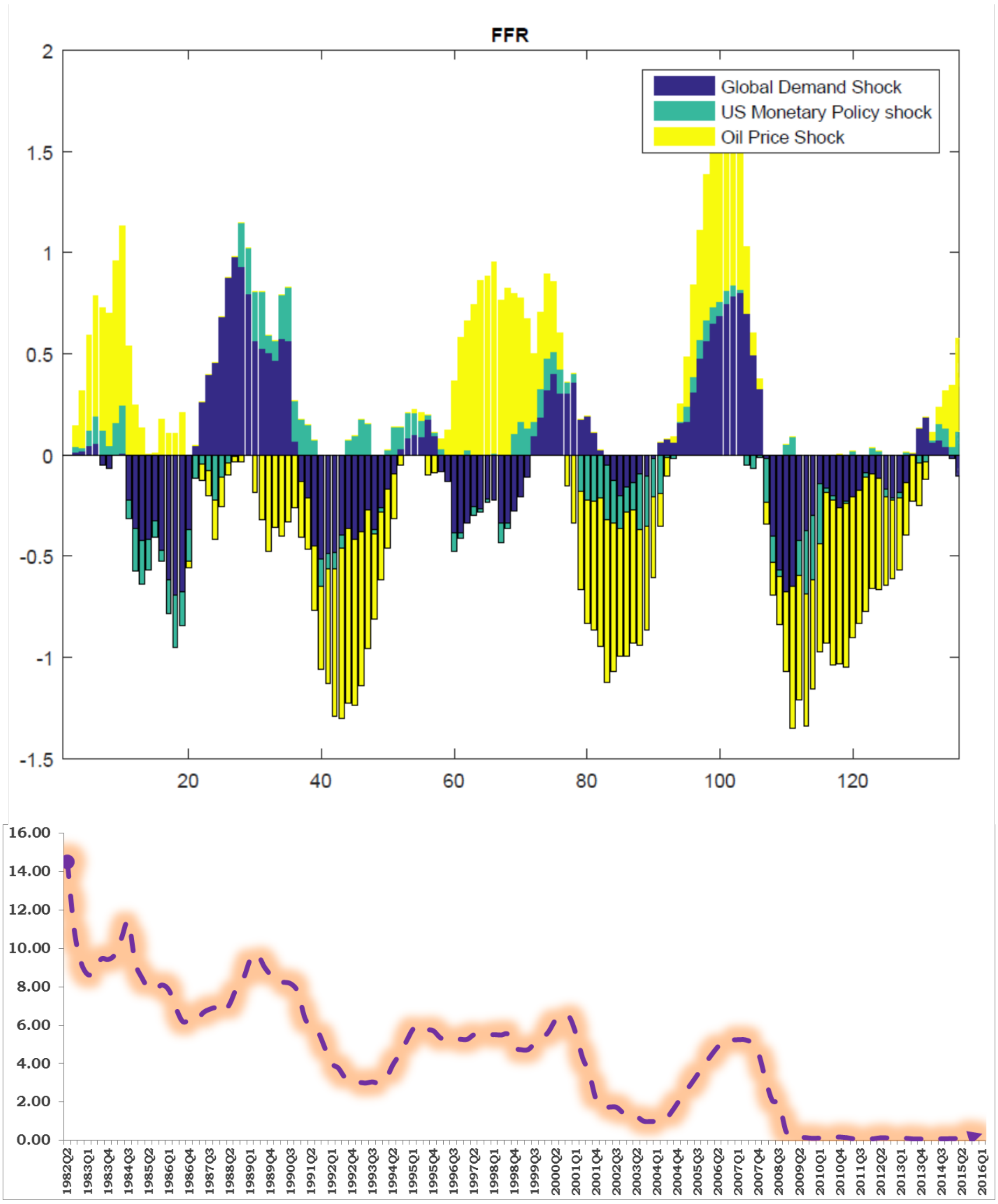

Figure 2.11: Historical Decomposition of US Federal Funds Rate and it's trend

Figure 2.11 indicates that oil price growth and global demand shocks exert significant influence on the evolution of the US federal funds rate. Oil price shocks dominate as the main driver of the US monetary policy stance. Curiously, however, even when the US monetary policy was at the zero-lower bound, oil price shocks still predominates as a key contributor to the US monetary policy.

Figure 2.12: Historical Decomposition of Oil Price Growth and it's trend

In figure 2.12, it is difficult to pin down oil price growth to any particular dominant contributory shock. However, the global demand shock tend to generate more clusters than the rest of the shocks, thus, suggesting that global demand shock is an important determinant for oil price dynamics.

2.6.3.2 External shocks contributions to Domestic Business Cycle Fluctuations

Figures 2.13, 2.14, 2.15 and 2.16 reveal the contributions of the three identified external shocks to the Nigerian business cycle fluctuations via the domestic output growth, the domestic inflation, the terms of trade and the domestic interest rate for the period 1982Q2 - 2016Q1. The historical contributions of the decomposed shocks are displayed in the upper panels of each figure, while a trend chart of the underlining domestic variables that these shocks drive are plotted in the lower panels of the referenced figures.

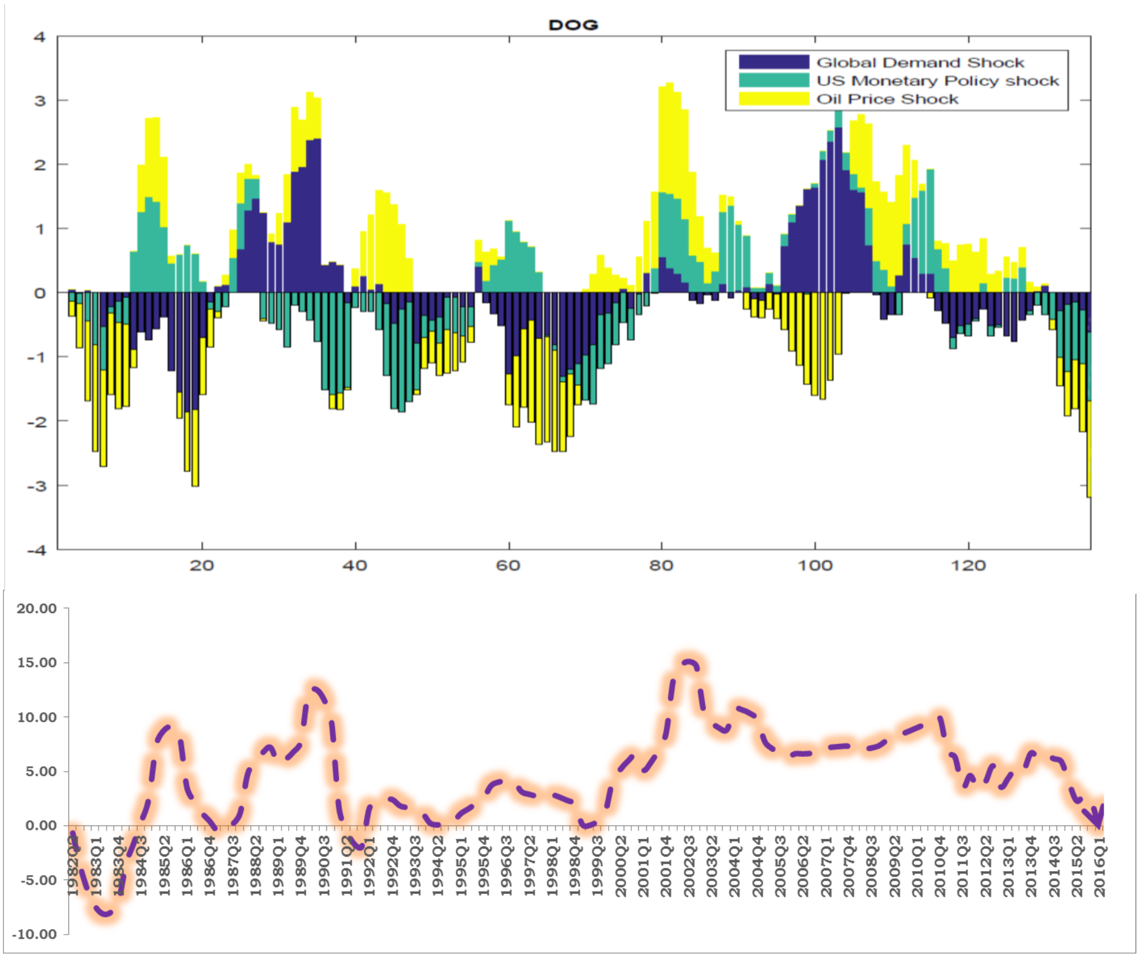

Figure 2.13: Historical Decomposition of Domestic Output Growth and it's trend

The decomposition of external shocks in figure 2.13 show that oil price shocks is the dominant driver of the domestic output growth in Nigeria. Positive oil price shocks are associated with high domestic output growth while negative oil price shocks are shown to correspond with moments of low and no output growth. For instance, oil price shocks induced by the 1990 Gulf war and the 2011 terrorist attack in the US, respectively, resulted in higher output growth, while the negative oil price shocks between 2014Q1 - 2016Q1 are associated with deceleration in domestic output growth. This evidences Nigeria's high dependency on oil and exposure to vulnerability arising from oil price volatility.

An equally important external shock is the global demand shock. The Nigerian business cycle appear to co-move with the global demand shock, indicating that the country has its share of the gains of a growing world economy and the pains of a shrinking world economy, respectively. However, the impact of the US monetary policy shock on Nigeria's domestic output growth is marginal.

From figure 2.13, we observe that, for the most parts of the sample, whenever both oil price and the US interest rate shocks are positive, domestic output growth tends to gain momentum; while an episode of high global demand and high interest rate does not seem to provide any significant impetus for domestic economic growth. Our results also indicate that during the Gulf War of 1990, the simultaneous positive global demand and oil price shocks, together with a negative US interest rate shock contributes to higher domestic economic growth.

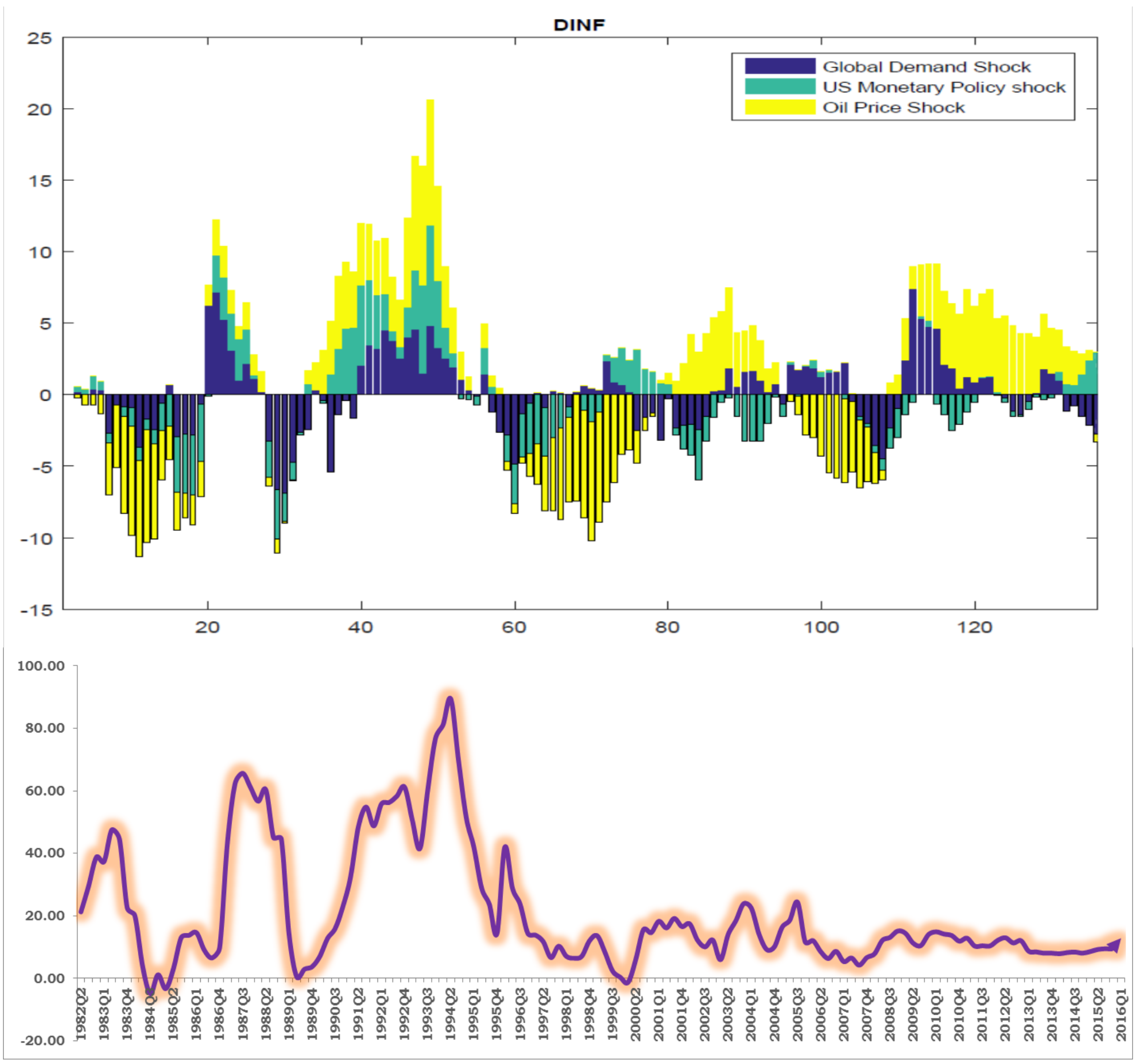

Figure 2.14: Historical Decomposition of Domestic Inflation and it's trend

Figure 2.14 also reveal oil price shock as the key contributor to inflation dynamics in Nigeria. Between 1982 and 1999 when inflation volatility was most pronounced, oil price shocks is shown to co-move with domestic inflation. This persisted through out the remaining parts of the sample, albeit, in a relatively low and stable inflation environment. A departure from this trend, however, ensued in 2015Q4, where negative oil price shock seems to drive inflation upward, mainly due to foreign exchange crisis owing to massive decline in oil earnings.

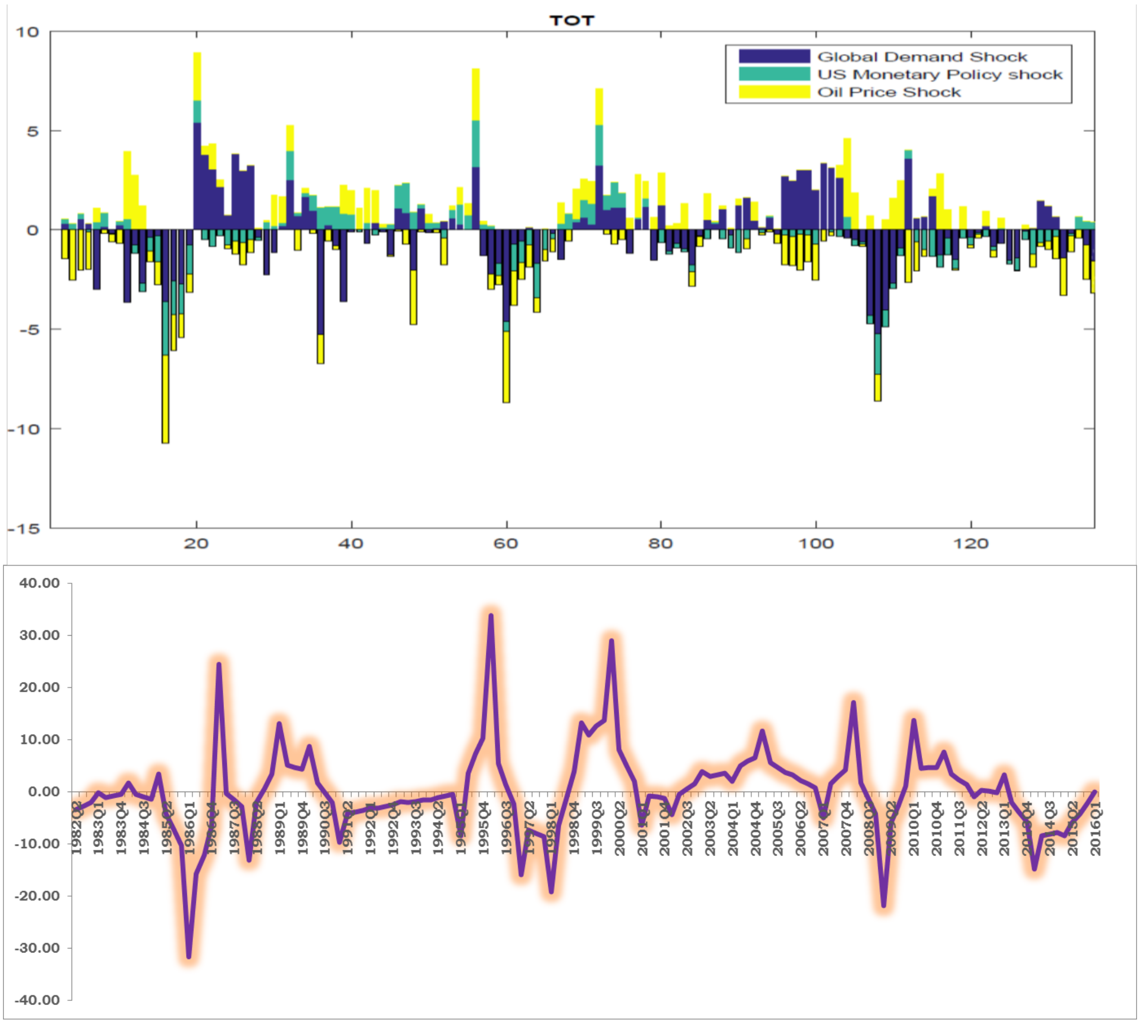

Figure 2.15: Historical Decomposition of Terms of Trade and it's trend

In the decomposition of the shocks driving terms of trade as shown in figure 2.15, oil price and global demand shocks appear to be the lead contributors. The terms of trade is a mirror image of the oil price, as oil export constitute the lion share of Nigeria's trade with the rest of the world. To reduce the oil component in the terms of trade, the non-oil component of the terms of trade must increase significantly.

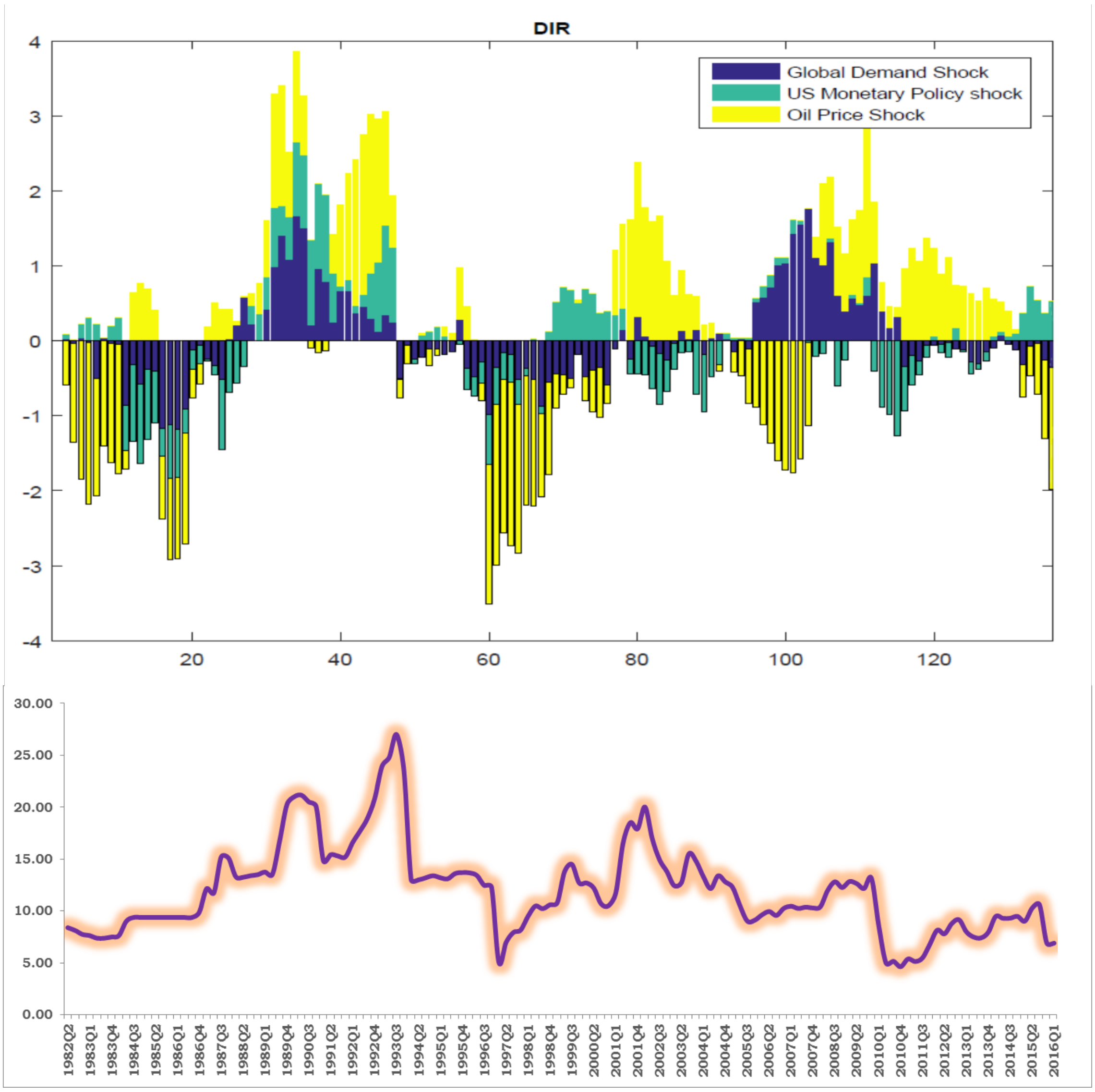

Figure 2.16: Historical Decomposition of Domestic Interest Rate and it's trend

The result in figure 2.16 reveal that the central bank of Nigeria, in setting the interest rate, tend to observe oil price movement, as episodes of positive oil price shocks are associated with tight monetary policy. Higher oil price and earnings provides impetus for increased government expenditure and raises the concern about inflation. At such times, the banking system experiences excess money supply which tends to encourage increased demand for imports and foreign exchange pressure. Thus, compelling an interest rate raise by the central bank in order to contain inflation.

2.7 Conclusion

We employ a sign restricted structural vector autoregressive (SVAR) model to examine the role of external shocks in Nigeria's business cycle evolution. Our identification structure reflect findings by Mumtaz & Surico (2009), Kilian & Lewis (2011), Olayeni (2009a) and Allegret & Benkhodja (2015). Three external shocks were identified in a seven variable SVAR model. Our baseline estimation spans from 1982Q1 - 2016Q1 while the robustness sample period is 1982Q2 - 2007Q4. The robustness exercise is meant to account for the possible effect of the global financial crisis on the Nigerian business cycle.

Our results indicate that the global demand and the oil price shocks dominate as drivers of the Nigerian business cycle. The effect of the global demand shock is most profound on domestic output and inflation while oil price shock exert the most influence on domestic interest rate and the terms of trade. Inference from our robustness exercise suggest that macroeconomic vulnerability associated with a negative global demand shock is a systematic one, given that the global financial crisis had no effect on the response of domestic output growth and interest rate to the shock. However, the financial crisis amplified domestic inflation's response to global demand shock, thus resulting to higher inflation volatility. The US monetary policy shock had a marginal negative effect on domestic output growth while significant positive inflation response came after a lag. Inflation response can be traced to the exchange rate effect induced by possible capital outflow in response to the higher interest rate in the US.

Similar to our results, Adolfson & Walentin (2013) showed that external demand shock is a significant driver of the Swedish business cycle, while Broda & Tille (2003) concludes that a significant proportion of output volatility in developing economies is accounted for by terms of trade shocks. These outcomes are confirmed in our study if the terms of trade is proxied by the oil price. Contrary to our findings, Rafiq (2011) reports that the US business cycle does not cause output fluctuations in emerging market oil-exporting economies. However, our results align with Rafiq (2011) on the close similarity between responses of oil price and terms of trade to foreign shocks in oil-exporting emerging countries. Conclusion by Philip & Akintoye (2006) and Omisakin (2008) that the effect of oil price shock on Nigeria's business cycle process is insignificant cannot be validated in our results and those obtained by Umar & Kilishi (2010) and Akpan (2009); which show that oil price shock is consequential for the Nigerian business cycle. We have extended the literature by widening the scope of external shock (oil price shock) mainly studied for Nigeria, to include global demand and US monetary policy shocks.

Our results have some modest implications for macroeconomic policy. Considering the dominant effect of the global demand shock and its persistence through the period of the global financial crisis, policies should be implemented to maximise gains from positive global demand shocks to achieve high growth rates and savings as a form of insurance against the potential debilitating effect of negative global demand shocks. Evidence that Nigeria's output growth tend to mimic oil price movement suggest vulnerability to oil price shocks. Also, given that oil price shock constitute the main external driver of inflation, which became more volatile during the global financial crisis; oil dependent emerging economies require policies oriented toward domestic resilience to oil shocks.

A path to attaining reduced exposure to oil shocks in oil exporting economies may be by delinking the overall economic performance from oil activity. Some advanced and middle income oil producing countries resolved this challenge through adherence to strict fiscal rules and the operation of sovereign wealth fund for oil revenues management. Industrialization can help diversify the revenue base of an oil economy, which in turn reduces the degree of dependence on oil sector performance.

Chapter 3

Oil Price Shocks and Optimal Monetary Policy in an Oil-rich Emerging Economy

Appendix 6B: Statement of Authorship

This declaration concerns the article entitled:			
Oil Price Shocks and Optimal Monetary Policy in an Oil-rich Emerging Economy			
Publication status (tick one) **Draft manuscript** [x] **Submitted** [ ] **In review** [ ] **Accepted** [ ] **Published** [ ]			
Publication details (reference)			
Copyright status (tick the appropriate statement) I hold the copyright for this material [x] Copyright is retained by the publisher, but I have been given permission to replicate the material here [ ]			
Candidate's contribution to the paper (provide details, and also indicate as a percentage)	The candidate contributed to / considerably contributed to / predominantly executed the… Formulation of ideas: 100% Design of methodology: 100% Experimental work: 100% Presentation of data in journal format: 100%		
Statement from Candidate	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature.		
Signed	Sunday Oladunni	**Date**	25/09/2019

3.1 Introduction

Recurrent episodes of oil price shocks generated considerable interest among policymakers and researchers in many countries on the appropriate monetary policy responses to mitigate the effects of such shocks. However, the literature mainly centers on the evolution of oil price shocks, their distortionary effects and the consequent role of monetary policy in oil-importing industrial economies[1]. Moreover, only a limited number of studies[2] employ micro-founded models to analyze this phenomenon; and even fewer analyze oil exporting emerging economies. Therefore, there is a gap in the literature on the transmission and dynamic effects of oil price shocks in oil exporting emerging economies and the optimal monetary policy response to oil price shocks.

Monetary policy design and implementation in oil exporting small open economies often runs into troubled waters whenever significant and persistent oil price shock occur. Particularly, macroeconomic conditions in these economies tend to move in tandem with the oscillatory patterns of the oil price. This comes with dire consequences for macroeconomic stabilization and welfare. Oil-dependent economies come under pressure whenever the price of oil plummets and they reap wind-falls when oil prices rise. Whereas the negative effect of sustained drop in oil prices is easily seen through worsening macroeconomic performance, the effect of higher oil prices remain open to debate in these economies. The Dutch disease and resource curse syndromes are commonplace in a number of resource-rich economies, thus making the question about the exact long-run effects of increase in commodity prices on resource endowed emerging economies a pertinent one. Vulnerabilities in these economies tend to undermine the potential long term benefits of increases in oil price.

Gali & Monacelli (2005)'s contribution to the discourse on monetary policy modeling in small open economies highlighted the role of the exchange rate in the transmission process of shocks of foreign origin in a small open economy. They explore alternative monetary policy rules for achieving macroeconomic stabilization in small open economies. Ever since, there has been a growing appetite in the literature to embed commodity dynamics in small open economies (SOE) DSGE models and to evaluate monetary policy given terms of trade shocks in commodity-dependent economies.

Within the context of an oil importer, Leduc & Sill (2001b) simulated a dynamic stochastic general equilibrium (DSGE) model and reports that, although

[1] See Bernanke *et al.* (1997b); Barsky & Kilian (2001); Lee & Ni (2002); Hamilton (2003); Kilian (2008); Blanchard *et al.* (2010); Killian & Lewis (2011), etc)

[2] Such as Kim & Loungani (1992b), Backus & Crucini (2000), Leduc & Sill (2001a), Devereux *et al.* (2006), Romero (2008), Bodenstein *et al.* (2012)

policy makers cannot totally insulate their economies from oil-price shocks induced consequences, their response to the shock is crucial in determining how profoundly the shock will impact their economies. They show that a response via interest rate increase may amplify the effect of an oil shock on output, while an accommodatory monetary policy through money growth may help contain the size of the impact. Medina & Soto (2005) incorporated oil in dynamic stochastic general equilibrium (DSGE) model estimated for Chile and finds that oil price shock induced output contraction and inflationary pressure; and that, the monetary policy rule that responds to wage rigidity is next to the second best outcome; while indicating that a full inflation stabilization policy response from the central bank is at a considerable output cost.

Romero (2008) modeled an oil producing economy in a two-sector DSGE model featuring a representative oil firm and an oil-utilizing final goods firm and showed that that oil price shock tends to exacerbate inflation pressures, resulting from the standard cost-push effect and a marginal cost perturbing wealth effect. In addition, he finds that the simple policy rule that responds to consumption is welfare-superior. Ferrero & Seneca (2015) constructed a DSGE model for Norway with a modeling framework that accommodates linkages and spillovers between the oil producing sector and the rest of the economy; and a fiscal policy rule that allows for a sovereign wealth fund for warehousing oil receipts. They suggest that the central bank should respond to a negative oil price shock by reducing interest rate, while indicating that domestic inflation stabilization is welfare consistent.

A number of studies on Middle East and North Africa (MENA) countries have shed light on the dynamic interactions between oil price shocks and macroeconomic dynamics in the region. For instance, in a stylized DSGE model estimated for Algeria, Allegret & Benkhodja (2015) employ a framework that accommodates a domestic oil price rule for imported refined oil, with a parameter whose value can be set to either allow for full subsidy (which mutes exchange rate pass-through) or allow for a complete pass-through of oil price shocks to the domestic economy (with a zero subsidy). Their result indicates that in the presence of oil price shock, targeting core inflation provides the best outcome for economic stabilization and social welfare in Algeria. Meanwhile, in an earlier study on Algeria, Benkhodja (2014) recommends inflation targeting under a flexible exchange rate system as the most appropriate way to insulate an oil exporting economy from the Dutch disease. In addition, Omran *et al.* (2015) follows Romero (2008) to model oil as a productive factor in the non-oil sector, identifies multiple shocks and reports that domestic inflation targeting rule is welfare superior given a productivity shock, while the exchange rate targeting rule maximizes welfare the most given oil price shock in Iran.

Hove *et al.* (2015) evaluates alternative monetary policy setups given terms of trade shock in a multi-sector commodity exporting SOE DSGE model calibrated for South Africa. Their framework explores production in the foreign economy and reflects the small open economy's commodity export in the foreign economy's production dynamics. Their findings suggest that, in the event of a shock to the terms of trade, the CPI targeting monetary policy rule will produce the highest support for macroeconomic stabilization and welfare, though at a cost of high exchange rate volatility. More recently, Algozhina (2016) in a SOE DSGE model with monetary and fiscal instruments, multi-sector production, heterogeneous households and fiscal savings, allows for foreign exchange reserves in the uncovered interest rate (UIP) equation and finds that given a negative oil price shock, a pro-cyclical fiscal policy stance can be combined with a CPI inflation targeting monetary rule in a flexible exchange rate environment[3] to achieve optimum welfare outcomes.

Olomola & Adejumo (2006) using a structural vectorautoregressive (VAR) method examined the effect of oil price shocks on the Nigerian economy and finds that oil price shock did not impact output and inflation, but significantly influenced the real exchange rate. Whereas Aliyu (2009) using the Johansen VAR-based co-integration technique reports that a unidirectional causality flows from oil price to real GDP while causality between the real exchange rate and the real gross domestic product is bidirectional. He also finds that real economic growth is positively influenced by oil price shock and exchange rate appreciation in Nigeria. Adebiyi *et al.* (2009), in a multivariate VAR analysis indicates stock market's negative ultra sensitivity to the real oil price shock; as the shock elicit an immediate and significant negative real stock returns. In the same vein, Iwayemi & Fowowe (2011) based on results from VAR analysis finds that positive oil price shocks do not have significant effect on key macroeconomic variables in Nigeria. However, their findings reveal the presence of asymmetric effects, as negative oil price shocks impact output and the real exchange rate significantly. Results of these empirical investigations on oil price shock and macroeconomic behaviour in Nigeria demonstrates the lack of consensus in the literature, apart from the fact that all of the modeling techniques employed do suffer from Lucas Jr (1976)'s critique.

Despite Nigeria's status as a the largest economy in Africa and a top tier player in oil exporting circles, the Nigeria-focused DSGE literature is rather sparse; with only a handful providing inconclusive insights on external shocks transmission to the economy and the optimal path for monetary policy given external shocks. Olekah & Oyaromade (2007) in their pioneering work on Nigeria, specified a small scale open economy DSGE model a la Lubik & Schorfheide (2006) and Fukac *et al.* (2006) but only performed a pseudo-estimation using the vectorautoregressive (VAR) analysis and reports that inflation is sensitive mainly to output changes and that interest rate

[3]Without intervention in the foreign exchange market

volatility is traceable to exchange rate and inflation shocks in Nigeria. Alege (2008) incorporates an export sector into Nason & Cogley (1994) and Schorfheide (2000) to estimate a model to characterize the Nigerian business cycle and finds that technology, monetary and export shocks have effects on the Nigerian business cycle and that the link between the macro economy and the external sector is weak. Olayeni (2009a) using a Bayesian DSGE-VAR estimation approach, analyses monetary policy shocks under four alternative formulations and finds that the monetary authority in Nigeria is business cycle-conscious and that the policy maker's benign response to exchange rate fluctuations accounts for the observed exchange rate overshooting and persistence. Thus, the paper recommends that monetary policy should reflect strong inertia and be more aggressive towards exchange rate. Adebiyi & Mordi (2012) estimates a DSGE model to examine the pass-through from exchange rate and oil price to domestic economy and finds evidence in support of a small and incomplete exchange rate pass-through to domestic inflation; while their findings on exchange rate response to oil price shock is rather less definitive, as it was negative on impact and then turned positive in the third quarter with an extended period of persistence. Iklaga (2017) [4], in a Smets & Wouters (2003)-type model modified for Nigeria and which features heterogeneous household, capital, government and treats oil sector as exogenous, finds that exchange rate appreciation, consumption increase, aggregate output contraction and employment drop results from a positive oil price shock. Furthermore, in related work, he finds that the optimized monetary policy rule that targets real wage is superior to other optimized and the sub-optimal rules in terms of welfare, albeit, at a cost of high interest rate volatility. Rasaki (2017) employ the Bayesian technique to estimate a small open economy DSGE model for Nigeria, which embeds a non-separable money in the utility function following Andrés *et al.* (2006), to allow monetary aggregate an active role in the economy. Their results suggests that inflation in Nigeria is a monetary phenomenon, price stickiness is observed and monetary policy reacts to exchange rate movements; while foreign inflation, external debt and exchange rate shocks are shown to drive output in Nigeria.

Evidently, the literature on the pattern of interactions between oil price shock and domestic business cycle variables in Nigeria is too limited to allow a consensus of ideas that can guide policy design and implementation in a robust manner. Additionally, till date there is only one known piece of work[5] where attempt has been made to trace the optimal path for monetary policy in Nigeria given oil price shock. Policymakers require a robust understanding of the dynamic interactions

[4] I refer to chapter 3 and 4 of the PhD dissertation by Fred Ogli Iklaga published online via epubs.surrey.ac.uk in 2016

[5] Iklaga (2017)

between oil price movements and macroeconomic aggregates in order to design effective monetary policy to achieve optimal macroeconomic stabilization and welfare during good and bad[6] times. Alternative routes to monetary policy optimization based on micro-founded analysis should not be obscure to policy makers, especially in economies with inherent external sector vulnerabilities.

Whereas Iklaga (2017) and Rasaki (2017) followed Smets & Wouters (2003) and Andrés *et al.* (2006), respectively to estimate SOE DSGE models for Nigeria; we leverage Gali & Monacelli (2005) and Hove *et al.* (2015) to construct and simulate a multi-sector new Keynesian small open economy DSGE model that feature explicit oil production and analyses oil price shock and optimal monetary policy exercise. The SOE model of Gali & Monacelli (2005) has become the benchmark model for studying fundamental features of SOEs and monetary policy options for achieving welfare maximization. Given key SOE's model building blocks, we added oil and foreign production sectors to highlight the interaction between the SOE and the foreign economy production sectors, a strategy which ensures SOE's oil export feature in foreign production as a key input.

The model is calibrated to capture some broad features of oil producing emerging economies like Nigeria. The representative household seeks to maximize utility from consumption and hours of work subject to a budget constraint, price is sticky in the domestic non-oil production sector while the oil sector is assumed to operate in a perfectly competitive environment. All domestic oil output are exported and oil sector is the only export sector. Oil resource is treated as an endowment in the small open economy, requiring only labor employment to exploit. We analyze the effects of a positive oil price shock on macroeconomic aggregates and the optimal monetary policy path given the shock. The central bank sets up monetary policy to respond to output gap, inflation and exchange rate volatility via a Taylor (1993)-type monetary policy reaction function. The model is solved and then simulated with a 10 percent positive oil price shock under alternative monetary policy rule specifications. Given a range of ten alternative policymaker's preferences for constructing the loss equation, we analyze optimal monetary policy under the optimized simple rules (OSR), discretion and commitment policies.

Consequently, we find evidence of Dutch disease in the economy. Both the non-tradable and total output contracted in response to a positive oil price shock, and this is most amplified under the CPI targeting monetary rule. The significant increase in oil output somewhat offsets the decline in non-oil output leading to higher employment and consumption. The exchange rate is associated with a marked appreciation

[6]The good times are periods when the economy is hit by a favorable shock, like increases in oil price or higher global incomes and bad times are those associated with unfavorable events like oil price slumps, etc

while the inflation threat was benign on impact, but later became manifest. The monetary authority lowered the interest rate in response to the Dutch disease. The domestic inflation targeting (DIT) rule is found to be welfare-superior in the class of the optimized simple rules (OSR) while the commitment policy dominates both discretionary policy and the optimized simple rules.

The introductory section is followed by section 2, which discusses the model in detail. Section 3 explores model calibration, solution and simulation, while in section 4, we analyze impulse response and volatility results. In section 5, we treat optimal monetary policy and section 6 concludes the chapter.

3.2 The Model

3.2.1 Model Outline

We model a two-sector small open economy[7] endowed with an oil resource. There is a representative household which consumes both foreign and domestic goods, two classes of representative firms; one producing non-traded goods and the other producing oil exclusively for export. There is a central bank that cares about private agents' welfare and implements monetary policy to achieve this objective. The domestic economy interacts with the rest of the world (ROW) via export of oil to and import of consumption goods from the ROW. The oil producing firm operates in a perfectly competitive market while the non-tradable goods producing firm operates as a monopolistic competitor.

The inclusion of an oil sector in the model enriches the original Gali & Monacelli (2005)-type of small open economy new Keynesian DSGE models and allows for the exploration of possible interactions between the oil export-oriented sector and the wider domestic economy. A two-sector model can provide better understanding of the nature and variety of shocks policy makers should anticipate and the appropriate response whenever these shocks hits the economy. This is crucial in the light of the fact that macroeconomic fundamentals in oil exporting economies are largely driven by price and supply dynamics in the oil market.

The model features price stickiness a la Calvo (1983b) in the domestic (non-tradable goods) sector; thus allowing for inflation and a role for monetary policy, accordingly. In the tradable sector, the law of one price holds, thus there is no separate Philip's curve for imports; although the general price index still captures imported component of inflation. Also, a complete assets market is assumed, hence there are no financial frictions in the model. It also features complete exchange rate pass-through. The pricing system for the oil firm is such that it is a price taker in a dollar pricing world. Therefore, dollar oil price is taken as given and typically, the firm makes a zero profit.

Capital and investment do not feature in the model as is typical of many small open economy DSGE models for optimal policy analysis. Steinsson (2003) in a closed economy model for optimal monetary policy with inflation persistence, abstracts from investment and capital accumulation by assuming a fixed endowment of non-depreciating capital. For a small open economy, Mccallum & Nelson (1999) argue that, the stock of capital is inconsequential for the economy's dynamics since the contribution of capital changes to the business cycle fluctuations is small. In line with the Gali & Monacelli (2005) tradition, firm's production function incorporates

[7] As shown in figure 3.1

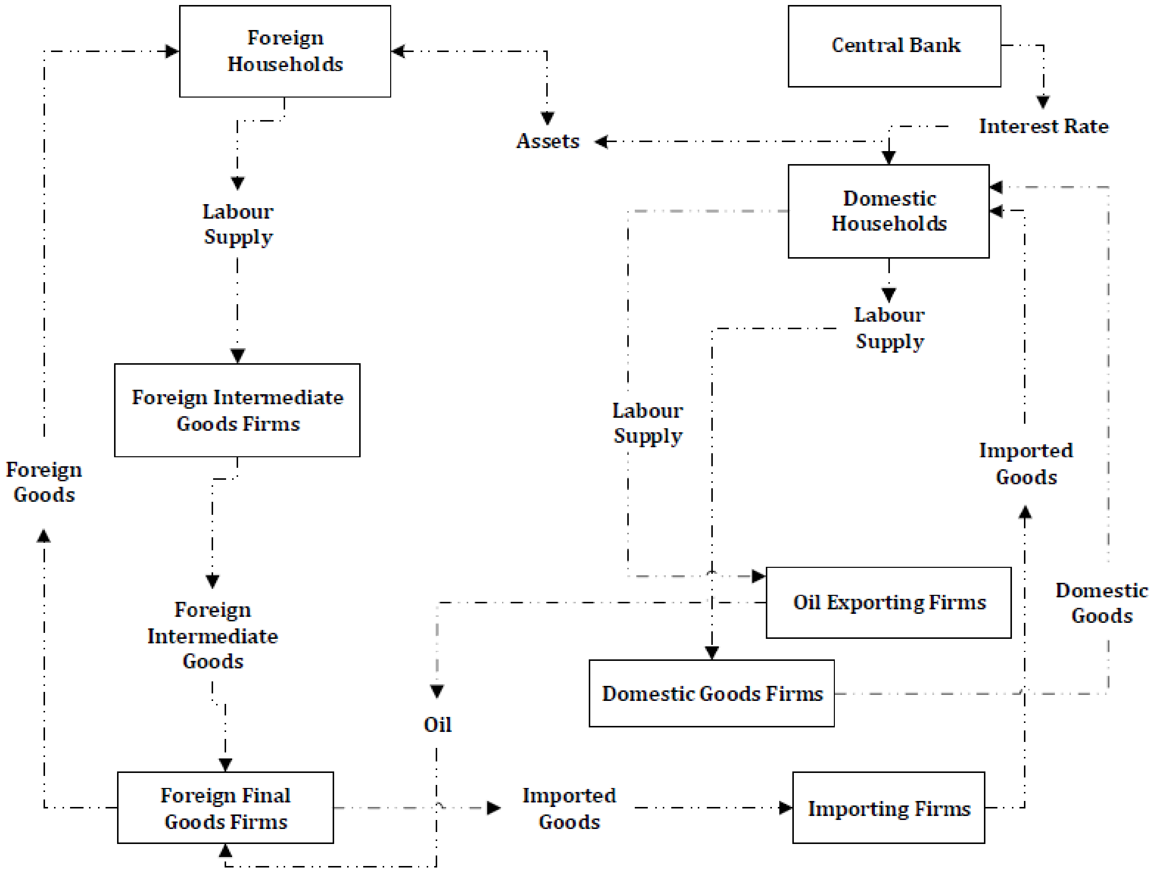

Figure 3.1: Overview of Model

only labour input; except for the foreign final goods firm that utilizes oil and a foreign intermediate good as inputs. Households enjoy domestic firm's ownership for profits and supply labour to both domestic and oil firms for wages. Labour is perfectly mobile across all sectors. Monetary policy is modeled using a typical Taylor rule, augmented with the exchange rate and a smoothing parameter. Our optimal monetary policy exercise compares outcomes under optimized simple rules, discretion and commitment policies given an oil price shock.

3.2.2 Household Behaviour

3.2.2.1 Representative Household Problem

We model an economy populated by an infinite number of atomistic, but identical households. Thus, a representative household approximates preferences of all households with respect to consumption and hours of work. The representative household seeks to maximize utility, given an inter-temporal budget constraint. The utility function is of the form:

$$V = E_0 \sum_{t=0}^{\infty} \beta^t U_t(C_t, L_t) \tag{3.1}$$

$$U_t(.) = \frac{C_t^{1-\eta}}{1-\eta} - \frac{L_t^{1+\varrho}}{1+\varrho} \tag{3.2}$$

where β is the discount factor, C_t is a composite index of consumption goods, L_t are hours of work; η is the relative risk aversion coefficient, otherwise referred to as the inverse of the elasticity of inter-temporal substitution, and ϱ is the elasticity of the marginal dis-utility of labour. Both η and ϱ take, strictly, positive values.

The household's composite consumption C_t includes non-tradable (domestic) good, C_t^h and imported good, C_t^f. Using the Dixit & Stiglitz (1977) aggregator, the composite consumption for the economy is expressed as:

$$C_t = [(\Psi)^{\frac{1}{\upsilon}}(C_t^h)^{\frac{\upsilon-1}{\upsilon}} + (1-\Psi)^{\frac{1}{\upsilon}}(C_t^f)^{\frac{\upsilon-1}{\upsilon}}]^{\frac{\upsilon}{\upsilon-1}} \tag{3.3}$$

where the parameter Ψ represents the weight or share of domestically produced, non-tradable goods in total consumption, which may be interpreted as the "home bias" coefficient; while $1-\Psi$ is the weight of foreign goods in total consumption, which denotes the import share in total domestic consumption and could be termed as the degree of openness index for this economy. The parameter $\upsilon > 0$ is the elasticity of substitution between the consumption of domestically produced non-tradable goods C_t^h and imported goods C_t^f. It is a measure of substitutability between non-tradables and imports. Consumption of non-tradable and imported goods are defined as follows, using the constant elasticity of substitution (CES) aggregators:

$$C_t^h = \left(\int_0^1 C_t^h(i)^{\frac{\nu-1}{\nu}} di\right)^{\frac{\nu}{\nu-1}}, \qquad C_t^f = \left(\int_0^1 C_t^f(i)^{\frac{\nu-1}{\nu}} di\right)^{\frac{\nu}{\nu-1}} \tag{3.4}$$

where $C_t^h(i)$ and $C_t^f(i)$ denotes consumption of home and foreign goods of variety (i) by the representative household in the small open economy. The parameter $\nu > 1$ is the elasticity of substitution within each goods category (i.e. domestic goods category and imported goods category), and it differs from υ which depicts the consumer's taste for variety between consumption of domestic and imported goods. Whereas, ν is the elasticity of substitution between variety of commodities within each of the two goods categories, υ operates between the two broad categories of goods. Put differently, υ is the elasticity of demand between the two categories of consumer goods while ν is the elasticity of demand within each category of goods.

Given that individual price indices for each category of goods in the consumption basket is defined as $P_t^h = \left(\int_0^1 P_t^h(i)^{1-\nu}di\right)^{\frac{1}{1-\nu}}$ and $P_t^f = \left(\int_0^1 P_t^f(i)^{1-\nu}di\right)^{\frac{1}{1-\nu}}$, respectively; the household optimal allocation can be obtained by minimizing expenditures relating to each category of goods, subject to their respective CES consumption aggregators. Thus, the consumer will do the following for each category of goods:

$$Minimise \quad \rightarrow \quad \int_0^1 P_t^h(i)C_t^h(i)di \qquad s.t. \qquad C_t^h = \left(\int_0^1 C_t^h(i)^{\frac{\nu-1}{\nu}}di\right)^{\frac{\nu}{\nu-1}},$$

$$Minimise \quad \rightarrow \quad \int_0^1 P_t^f(i)C_t^f(i)di \qquad s.t. \qquad C_t^f = \left(\int_0^1 C_t^f(i)^{\frac{\nu-1}{\nu}}di\right)^{\frac{\nu}{\nu-1}}$$

After minimization, the household optimal allocation for each category of goods results in the following demand functions:

$$C_t^h(i) = \left(\frac{P_t^h(i)}{P_t^h}\right)^{-\nu} C_t^h, \qquad C_t^f(i) = \left(\frac{P_t^f(i)}{P_t^f}\right)^{-\nu} C_t^f \tag{3.5}$$

Household minimum expenditure on non-tradable and imported goods can be expressed as follows:

$$\int_0^1 (P_t^h(i)C_t^h(i)di \;=\; P_t^hC_t^h), \qquad \int_0^1 (P_t^f(i)C_t^f(i)di = P_t^fC_t^f) \tag{3.6}$$

When the total consumption cost is minimized subject to the composite consumption index, the optimal household expenditure allocation, reflecting the weights of non-tradables and imports in the entire consumption basket, respectively will yield the following demand functions:

$$C_t^h \;=\; \Psi\left(\frac{P_t^h}{P_t}\right)^{-\upsilon} C_t, \qquad C_t^f = (1-\Psi)\left(\frac{P_t^f}{P_t}\right)^{-\upsilon} C_t \tag{3.7}$$

Going forward, we apply the Uhlig (1995)'s approach to perform log-linearization on the characterizing equations of the model. This approach involves taking the log deviation of each expression around their steady-state values. Each lower case variable capped with tilde should be taken as the log-deviation of the corresponding upper case variable from its steady state value.

In log-linearized forms, the demand functions in 3.7 become:

$$\tilde{c_t}^h = -\upsilon\left(\tilde{p}_t^h - \tilde{p}_t\right) + \tilde{c}_t, \qquad \tilde{c_t}^f = -\upsilon\left(\tilde{p}_t^f - \tilde{p}_t\right) + \tilde{c}_t \tag{3.8}$$

P_t is the overall (consumer) price index, and it is defined as:

$$P_t = [\Psi(P_t^h)^{1-\upsilon} + (1-\Psi)(P_t^f)^{1-\upsilon}]^{\frac{1}{1-\upsilon}} \tag{3.9}$$

Consequently, the small open economy's household minimum total consumption expenditures will be:

$$P_t^h C_t^h + P_t^f C_t^f = P_t C_t \tag{3.10}$$

Performing a log-transformation on 3.9 we obtain a Consumer Price Index (CPI) in the Cobb-Douglas functional form as follows:

$$P_t = P_t^{h(\Psi)} P_t^{f(1-\Psi)} \tag{3.11}$$

Where Ψ and $1-\Psi$ are the weights associated with non-tradable and imported goods, respectively, in the overall domestic consumer price index.

When log-linearized, the price index becomes:

$$\tilde{p_t} = \Psi\tilde{p_t}^h + (1-\Psi)\tilde{p_t}^f \tag{3.12}$$

This produces a Consumer Price Index (CPI) that represents a weighted sum of prices of non-traded and imported goods in the economy.

3.2.2.2 Labour Supply and Consumption Euler Equations

The representative household inter-temporal budget constraint can be expressed as follows:

$$P_t C_t + E_t(\xi_{t+1} B_{t+1}) + \mathrm{T_t^l} \leq W_t L_t + B_t + \Pi_t \tag{3.13}$$

where $P_t C_t$ is the consumer's minimum total consumption expenditure, W_t is the wage rate, B_t is one period asset portfolio, B_{t+1} is the nominal pay-off of period $t+1$ from asset portfolio held at the end of period t. $E_t(\xi_{t+1})$ is defined as R_t^{-1} and it is the stochastic discount factor, R_t is the domestic interest rate, T^l is lump-sum tax and Π_t is profits transferred to household by the domestic monopolistically competitive firms. Labour wage is assumed to be the same in all sectors, and it is taken as given by the household. The representative household decides on consumption, labour and assets holding to maximize welfare (utility) subject to the prevailing inter-temporal budget constraint. A non-trivial solution is assumed, such that $C_t > 0$, $L_t > 0$ and $B_t > 0$.

Given the household budget constraint, the general set up of the household problem becomes:

$$\mathcal{L} = \sum_{\imath=0}^{\infty} \beta^{\imath} \left\{ U(C_t, L_t) - \lambda_t \left[P_t C_t + E_t(\xi_{t+1} B_{t+1}) + T_t^l - W_t L_t - B_t - \Pi_t \right] \right\} \quad (3.14)$$

Where λ_t is the Lagrangian multiplier capturing the marginal utility of wealth. Upon maximizing the Lagrangian multiplier with respect to consumption C_t, labour supply (hours of work) L_t and household's portfolio of assets B_t, we obtain the following first-order conditions (FOCs):

$$\frac{\partial \mathcal{L}}{\partial C_t} = C_t^{-\eta} - \lambda_t P_t = 0$$

$$\frac{\partial \mathcal{L}}{\partial L_t} = -L_t^{\varrho} + \lambda_t W_t = 0$$

$$\frac{\partial \mathcal{L}}{\partial B_t} = -\beta \lambda_{t+1} + \lambda_t E_t \xi_{t+1} = 0$$

Given the assumption that all households are identical, the optimization conditions (i.e. first order conditions) of the representative household holds for the aggregate economy and can be expressed as follows:

$$C_t^{-\eta} = \lambda_t P_t \quad (3.15)$$

$$L_t^{\varrho} = \lambda_t W_t \quad (3.16)$$

$$\lambda_t = \beta E_t \lambda_{t+1} R_t^{-1} \quad (3.17)$$

Substituting 3.16 in 3.15, we obtain 3.18 as follows:

$$C_t^{\eta} L_t^{\varrho} = \frac{W_t}{P_t} \quad (3.18)$$

This is the labour supply equation, an expression in which the marginal value of labour is equated to the marginal utility of consumption. It states that the relative price (real wage) of consumption-leisure should be equal to the marginal rate of substitution of leisure-consumption. The expression implies that, ceteris paribus, higher consumption is only possible if there is an increase in labour hours. To consume more, the household has to forfeit some leisure to work more. This underscores the trade-off between leisure and consumption. However, this also imply that consumption can increase if there is a rise in the real wage while the consumer enjoys the same level of leisure.

Equation 3.19 below is the Consumption Euler equation, which reflects the trade-off associated with the inter-temporal allocation of the household consumption and it is obtained by re-arranging equation 3.17, and substituting λ_t and λ_{t+1} respectively.

$$1 = \beta R_t E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\eta} \left(\frac{P_t}{P_{t+1}} \right) \right] \tag{3.19}$$

In equation 3.19, $\frac{1}{R_t}$ is the price of a one-period domestic currency denominated bond. R_t represents the gross interest rate on the bond. The consumption Euler equation underscores how interest rate influences the household decision either to consume more or less between periods. The consumer compares the utility derivable from consuming an additional amount now (t) with the utility expected from consuming more in future (t+1). In an environment where interest rate is expected to rise in future, consuming more today will be costly, hence, the willingness to wait and consume more in future.

The log-linearized versions of equations 3.18 and 3.19, are as follows:

$$\eta \tilde{c}_t + \varrho \tilde{l}_t = \tilde{w}_t - \tilde{p}_t \tag{3.20}$$

$$\tilde{c}_t = E_t \tilde{c}_{t+1} - \frac{1}{\eta} \left(\tilde{r}_t - \tilde{\pi}_{t+1} \right) \tag{3.21}$$

3.2.3 Domestic Firms Production

The economy is populated by two types of firms engaged in production activity. The first representative firm produces[8] oil entirely for export to the rest of the world (ROW) and the second firm is engaged in the production of non-tradable final goods. In essence, one firm operate in the export (tradable) sector while the other operate in the non-tradable sector. Activity relating to the firm in the non-tradable sector is denoted with the superscript (h) while that relating to the firm in the tradable sector is denoted with the superscript (o). A third class of non-producing firms exist in the economy, dealing in the importation of goods from the foreign economy for domestic consumption.

[8] Production here refers to mining of oil minerals from under the ground and beneath the sea for exports.

3.2.3.1 Firms in the tradable (oil) sector

The representative oil firm is assumed to operate in an international oil market deemed to be perfectly competitive. The firm employs only labour and it's production function evolves linearly as follows:

$$Y_t^o = Z_t^o L_t^o \tag{3.22}$$

where Y_t^o, Z_t^o and L_t^o is oil output, oil sector productivity variable and labour employed in the oil sector, respectively. Z_t^o, the productivity variable in the oil sector, is an exogenous autoregressive process of the form:

$$\ln(Z_t^o) = \rho_{z^o}\ln(Z_{t-1}^o) + \varepsilon_t^{Z^o} \qquad\qquad \varepsilon_t^{Z^o} \sim N(0, \sigma_z^2) \tag{3.23}$$

The oil firm minimizes cost subject to total output constraint, thus leading to the oil sector real marginal cost function as follows:

$$RMC_t^o = \frac{W_t}{Z_t^o P_t^o} \tag{3.24}$$

The equation for the oil sector's real marginal cost (RMC_t^o) in (24) represents the firm's cost minimizing decision and can be expressed log-linearly as follows:

$$r\tilde{m}c_t^o = \tilde{w}_t - \tilde{z}_t^o - \tilde{p}_t^o \tag{3.25}$$

Given the perfect competition in the oil sector, we can derive the representative oil firm's price as:

$$P_t^o = NMC_t^o = \frac{W_t}{Z_t^o} \tag{3.26}$$

We can also, from 3.26 obtain $W_t = Z_t^o P^o$; where NMC_t^o and RMC_t^o in 3.24 and 3.26 refer to the nominal and real marginal costs in the oil sector, respectively; and W_t is the wage rate, while P_t^o is the domestic price of oil.

$$W_t = P_t^o Z_t^o \tag{3.27}$$

3.2.3.2 Firms in the non-tradable sector

In the non-oil sector, imperfectly competitive firms produce differentiated commodities entirely for domestic consumption. Hence, these goods are non-tradables. The non-tradable goods firms are subject to monopolistic competition and they utilize a linear production function as follows:

$$Y_t^h = Z_t^h L_t^h \tag{3.28}$$

where Y_t^h is the non-tradable goods output, Z_t^h is non-tradable sector productivity variable and L_t^h is the employment in the non-tradable sector. The productivity variable Z_t^h, being an exogenous autoregressive process is expressed as follows:

$$\ln(Z_t^h) = \rho_{z^h}\ln(Z_{t-1}^h) + \varepsilon_t^{Z^h} \qquad\qquad \varepsilon^{Z^h} \sim N(0, \sigma_z^2) \tag{3.29}$$

The firm's optimality condition resulting from cost minimization process in the non-tradable sector is as follows:

$$RMC_t^h = \frac{W_t}{Z_t^h P_t^h} \tag{3.30}$$

Where RMC_t^h is the non-tradable sector's real marginal cost and P_t^h is the non-tradable good's price. The log-linear version of the RMC_t^h is as follows:

$$r\tilde{m}c_t^h = \tilde{w}_t - \tilde{z}_t^h - \tilde{p}_t^h \tag{3.31}$$

From 3.30, we can obtain:

$$P_t^h = \frac{W_t}{Z_t^h RMC_t^h} \tag{3.32}$$

Recall that from 3.26, given perfect competition assumption in the oil sector, we obtain the expression:

$$W_t = Z_t^o P_t^o \tag{3.33}$$

Similarly, from 3.32 we derive:

$$W_t = P_t^h Z_t^h RMC_t^h \tag{3.34}$$

Assuming wage equalization in the tradable and non-tradable production sectors, equations 3.33 and 3.34 are used to derive the relative price of non-tradable goods to oil price as follows:

$$P_t^h = \frac{Z_t^o}{Z_t^h RMC_t^h} P_t^o \tag{3.35}$$

The log-linear version is:

$$\tilde{p_t}^h = \tilde{z}_t^o - \tilde{z}_t^h - r\tilde{m}c_t^h + \tilde{p}_t^o \tag{3.36}$$

Equation 3.35 indicates that the relative productivity in the two sectors, oil price and non-tradable real marginal cost are the determinants of non-tradable goods price. From this expression, it would seem, ceteris paribus, that higher oil price and improvement oil sector productivity can lead to increase in the price of non-tradable commodities. We can also infer ceteris paribus, that improvement in non-tradable sector productivity may induce lower price for non-tradable goods.

3.2.3.3 Importers

We assume the existence of a retailer importing foreign homogeneous good Y_t^f from the rest of the world at the foreign currency price P_t^{f*}. The imported good is packaged into a consumption good C_t^f at no extra cost and with a zero mark-up. The law of one price (LOOP) operates, such that the domestic price of imported goods is equivalent to the corresponding foreign price denominated by the nominal exchange rate. The domestic price of imports is expressed as follows:

$$P_t^f = \frac{P_t^{f*}}{S_t} \tag{3.37}$$

Where P_t^f is the domestic price of import and S_t is the nominal exchange rate. Equation 3.37 when log-linearized yields:

$$\tilde{p_t}^f = \tilde{p_t}^{f*} - \tilde{s}_t \tag{3.38}$$

The implication of the LOOP assumption is that there is complete pass-through, which ensures fluctuations in domestic price of imported goods fully reflect changes in foreign price of imports and the exchange rate dynamics.

3.2.4 Production in the Foreign Economy

The model features a perfectly competitive multi-sector foreign production block, comprising the foreign final goods sector, the foreign intermediate goods sector and the foreign non-tradable goods sector in the spirit of Cashin *et al.* (2004) and Hove *et al.* (2015). Foreign final goods firm uses oil from the SOE an input. It is commonplace in the SOE DSGE literature to assume key foreign economy linkages as a set of exogenous processes, rather than explore the micro-founded equilibrium dynamics. Similar to the domestic economy, perfect mobility of labour across the three foreign production sectors and the consequent cross sectors wage equalization is assumed.

3.2.4.1 Production in the foreign intermediate and non-tradable goods sectors

Firms in the foreign intermediate and non-tradable goods production sectors employ linear production technologies. Production function in the foreign non-tradable goods sector is given as:

$$Y_t^{h*} = Z_t^{h*} L_t^{h*} \tag{3.39}$$

Where Y_t^{h*}, Z_t^{h*} and L_t^{h*} represents foreign non-tradable output, foreign non-tradable sector productivity variable and employment in the foreign non-tradable sector, respectively. Z_t^{h*} follows an AR(1) exogenous process, which when expressed in logarithms yield the following:

$$\ln(Z_t^{h*}) = \rho_{z^{h*}} \ln(Z_{t-1}^{h*}) + \varepsilon_t^{Z^{h*}} \quad \varepsilon_t^{Z^{h*}} \sim N(0, \sigma_{z^{h*}}^2) \tag{3.40}$$

In the same vein, the foreign intermediate goods production function is modeled linearly as follows:

$$Y_t^{I*} = Z_t^{I*} L_t^{I*} \tag{3.41}$$

Where Y_t^{I*}, Z_t^{I*} and L_t^{I*} are the foreign intermediate sector's output, productivity and employment, respectively. Z_t^{I*} is also characterized by an AR(1) exogenous process as follows:

$$\ln(Z_t^{I*}) = \rho_{z^{I*}} \ln(Z_{t-1}^{I*}) + \varepsilon_t^{Z^{I*}} \quad \varepsilon_t^{Z^{I*}} \sim N(0, \sigma_{z^{I*}}^2) \tag{3.42}$$

By equating the relative prices in the foreign non-tradable and foreign intermediate sectors $\left(\frac{P_t^{h*}}{P_t^{I*}}\right)$ to the relative productivity in the foreign intermediate and non-tradable goods sectors $\left(\frac{Z_t^{I*}}{Z_t^{h*}}\right)$, we can derive the following:

$$P_t^{h*} = \left(\frac{Z_t^{I*}}{Z_t^{h*}}\right) P_t^{I*} \tag{3.43}$$

This expresses the price of foreign non-tradables as a product of the relative productivity and foreign intermediate goods price.

3.2.4.2 Production in the foreign tradable goods sector

The foreign tradable goods production sector applies a Cobb-Douglas technology to combine oil imported from the SOE and other oil exporters and foreign produced intermediate good as inputs for the production of tradable goods. The production function is as follows:

$$Y^{f*} = Z_t^{f*} (Y_t^{o*})^{\zeta} (Y_t^{I*})^{1-\zeta} \tag{3.44}$$

Where Z_t^{f*} is the foreign tradable goods production sector total factor productivity, Y_t^{I*} is the foreign intermediate goods inputs and Y_t^{o*} is the foreign oil input, a fraction of which is imported from the SOE. The parameters ζ and $1-\zeta$ represent the shares of oil imports and foreign intermediate goods in foreign final goods production, respectively. The cost minimization exercise in the foreign tradable goods sector will result in a cost per unit of output in the following form:

$$P_t^{f*} = (P_t^{o*})^{\zeta}(P_t^{I*})^{1-\zeta} \tag{3.45}$$

Foreign final goods are assumed to be tradable, allowing its import by the small open economy. Consumption by foreign households is assumed to be symmetric with that of consumers in the domestic economy, thus resulting in an implied foreign consumer price index of the form:

$$P_t^{*} = P_t^{h*(\Psi^*)} P_t^{f*(1-\Psi^*)} \tag{3.46}$$

Where Ψ^* and $1-\Psi^*$ are the weights associated with non-tradable and imported goods, respectively, in the foreign economy's overall consumer price index.

3.2.5 Domestic Firms Price Setting

The non-tradable goods producing firm sets the price of its goods following Calvo (1983b)'s staggered pricing rule, which allows price adjustment with some probability. Consequently, at period (t), a firm type with the probability $1-\theta^h$ can optimally re-set price while another firm type with the probability θ^h can not re-set price every period and thus, constrained to maintain previous period price. It applies that $\theta^h \in (0,1)$ and θ^h is the measure of the degree of stickiness or nominal rigidity in the system. The bigger the stickiness parameter θ^h the less flexible prices are. Taking into account the pricing behaviour of these firms type, a general price index can be constructed as follows:

$$P_t^h = \left\{(1-\theta^h)(P_t^h)^{reset^{1-\mu}} + \theta^h(P_{t-1}^h)^{1-\mu}\right\}^{\frac{1}{1-\mu}} \tag{3.47}$$

Where $(P_t^h)^{reset}$ is the price of the firm that can re-optimize. The maximization problem of the optimizing firm can be set up as follows:

$$\begin{aligned}
&Max \sum_{t=0}^{\infty}(\theta^h)^k E_t\left\{\xi_{t+k}Y_{t+k}\left[(P_t^h)^{reset} - NMC_{t+k}^h\right]\right\} \\
&s.t. \\
&Y_{t+k} \leq \left(\frac{(P_t^h)^{reset}}{P_{t+k}^h}\right)^{-\mu}\left(C_{t+k}^h + (C_{t+k}^h)^{reset}\right)
\end{aligned} \tag{3.48}$$

Where $(\theta^h)^k E_t \xi_{t+k}$ and NMC_{t+k}^h represent the effective stochastic discount factor and the nominal marginal cost, respectively. By this expression, the fraction of firms that can reset prices try to maximize the discounted present value of profit flows subject to the total demand for domestic non-tradable goods. Substituting Y_{t+k} in 3.48 and factorizing accordingly, the first order condition with respect to $(P_t^h)^{reset}$ can be obtained:

$$Max \sum_{t=0}^{\infty} (\theta^h)^k E_t \left\{ \xi_{t+k} Y_{t+k} \left[(P_t^h)^{reset} - \frac{\mu}{1-\mu} NMC_{t+k}^h \right] \right\} = 0 \qquad (3.49)$$

A few steps of mathematical procedure is applied to derive a log-linear expression which depicts the domestic (non-tradable) goods inflation as a function of the one period ahead expected non-tradable inflation and the real marginal cost of the non-tradable firm. This is the non-tradable sector's New Keynesian Phillips curve equation or the non-tradable sector's New Keynesian aggregate supply relation. It is given as:

$$\tilde{\pi}_t^h = \beta E_t \tilde{\pi}_{t+1}^h + \kappa_t^h r\tilde{m}c_t^h \qquad (3.50)$$

Where $\kappa_t^h = \frac{(1-\beta\theta^h)(1-\theta^h)}{\theta^h}$, being the coefficient of the real marginal cost in the New Keynesian Phillips curve equation.

3.2.6 Real Exchange Rate, Oil Price and Imported Inflation

3.2.6.1 The Real Exchange Rate

We follow Cashin *et al.* (2004) to define the real exchange rate (Q_t) as the foreign price of domestic consumption basket ($S_t P_t$) relative to the foreign price of foreign consumption basket (P_t^*). Put differently, the real exchange rate is expressed as the foreign worth of domestic basket of goods relative to the foreign worth of foreign basket of goods. This is expressed as follows:

$$Q_t = \frac{S_t P_t}{P_t^*} \qquad (3.51)$$

Where S_t is the nominal exchange rate, P_t is the domestic price index and P_t^* is the foreign price index.

We assume that the law of one price prevails at both ends (i.e. imports and exports) of the domestic economy's tradable sector such that:

$$P_t^f = \frac{P_t^{f*}}{S_t}, \qquad P_t^o = \frac{P_t^{o*}}{S_t} \qquad (3.52)$$

Where P_t^{f*} and P_t^{o*} are the foreign prices of the small open economy's imports and exports (oil), respectively; while P_t^o is the domestic price of oil.

Using equations 3.35, 3.37 and 3.43 in 3.51, we derive the following real exchange rate expression:

$$Q_t = \left(\frac{P_t^{o*}}{P_t^{I*}} \frac{Z_t^o}{Z_t^{I*}} \frac{Z_t^{h*}}{Z_t^h} \right)^{\Psi} \left(\frac{1}{RMC_t^h} \right)^{\Psi} \tag{3.53}$$

Where $\frac{P_t^{o*}}{P_t^{I*}}$ is the terms of trade between the small open economy's foreign oil price and the foreign economy's intermediate goods price, $\frac{Z_t^o}{Z_t^{I*}}$ is the corresponding productivity differential between the domestic oil sector and foreign intermediate goods sector, and $\frac{Z_t^{h*}}{Z_t^h}$ is the productivity differential between foreign and domestic non-tradable sectors. The relative productivities in 3.53 reflect the Harrod-Balassa-Samuelson effect, a theoretical hypothesis credited to the combined contributions of Harrod (1933), Balassa (1964) and Samuelson (1964) on the real exchange rate, relative productivities, relative prices and wages in the non-tradable sector. The Harrod-Balassa-Samuelson Hypothesis posits that, assuming the law of one price hold in the tradable sectors, a shock to productivity in the tradable sector will cause wages to rise, resulting in non-tradable goods price increase and an eventual appreciation of the real exchange rate.

The foremost justification for the above real exchange rate derivation in equation 3.53 has its root in the literature[9] which establishes that the equilibrium real exchange rate is largely driven by the long-run evolution of some macroeconomic fundamentals like productivity differentials, terms of trade and real interest rate differentials. In line with this tradition, Cashin *et al.* (2004) show empirically that real commodity prices constitute the fundamental determinant of the real exchange rate in commodity-exporting countries. Hove *et al.* (2015) modifies Cashin *et al.* (2004)'s real exchange rate specification by incorporating the non-tradable goods firm's real marginal cost in a new Keynesian small open economy model that identifies commodity terms of trade shock. Following this tradition, we study how a positive shock to the dollar price of oil will affect the oil exporting SOE's business cycle variables within the Gali & Monacelli (2005) small open economy New Keynesian framework and then proceed to explore optimal monetary policy.

The log-linear representation of equation 3.53 is as follows:

$$\tilde{q}_t = \Psi \left(\tilde{p}_t^{o*} - \tilde{p}_t^{I*} + \tilde{z}_t^o - \tilde{z}_t^{I*} + \tilde{z}_t^{h*} - \tilde{z}_t^h - r\tilde{m}c_t^h \right) \tag{3.54}$$

3.2.6.2 Oil Price

The domestic price of oil is given as $P_t^o = \frac{P_t^{o*}}{S_t}$. In log-linear form, it becomes:

[9]See De Gregorio *et al.* (1994), Rogoff (1996), Chinn & Johnston (1996), Montiel (1997), Kalcheva & Oomes (2007) and Egert & Leonard (2008).

$$\tilde{p}_t^o = \tilde{p}_t^{o*} - \tilde{s}_t \tag{3.55}$$

Both foreign oil price and oil price inflation are treated as AR(1) exogenous processes as shown in 3.89 and 3.90, respectively.

3.2.6.3 Imported Inflation

Imported inflation is associated with foreign tradable goods, and can be derived with the first difference of equation 3.45 as follows:

$$P_t^{f*} - P_{t-1}^{f*} = (P_t^{o*} - P_{t-1}^{o*})^{\zeta^*}(P^{I*} - P_{t-1}^{I*})^{1-\zeta^*}$$

$$\pi_t^{f*} = (\pi_t^{o*})^{\zeta^*}\left(\pi_t^{I*}\right)^{1-\zeta^*} \tag{3.56}$$

The equation when expressed in log-linear version becomes:

$$\tilde{\pi}_t{}^{f*} = \zeta^*\tilde{\pi}_t{}^{o*} + (1-\zeta^*)\tilde{\pi}_t{}^{I*} \tag{3.57}$$

In the domestic economy, the log-linearized consumer price index (CPI) inflation equation is obtained from 3.12 as follows:

$$\tilde{\pi}_t = \Psi\tilde{\pi}_t{}^h + (1-\Psi)\tilde{\pi}_t{}^f \tag{3.58}$$

From equation 3.52, the imported component of the domestic CPI inflation equation yields the following log-linear expression:

$$\tilde{\pi}_t{}^f = \tilde{\pi}_t{}^{f*} - \triangle\tilde{s}_t \tag{3.59}$$

When we substitute $\tilde{\pi}_t{}^{f*}$ from equation 3.56 into equation 3.59, we derive:

$$\tilde{\pi}_t{}^f = \zeta^*\tilde{\pi}_t{}^{o*} + (1-\zeta^*)\tilde{\pi}_t{}^{I*} - \triangle\tilde{s}_t \tag{3.60}$$

Equation 3.60 is the modified imported inflation, which expresses imported inflation in the domestic economy as a function of foreign intermediate goods inflation, oil inflation in the foreign oil market and changes in the nominal exchange rate.

3.2.7 International Risk Sharing and the Uncovered Interest Rate Parity

We assume complete international financial markets, which guarantees domestic economic agents access to the international financial markets. In the same vein, foreign agents too can access the domestic financial markets. Trading in state-contingent international financial assets is facilitated. Consequently, domestic agents are able to smooth consumption through subscription to domestic and foreign securities. Assuming both domestic and foreign households exhibit the same preferences and stochastic discount factors, consequent upon which the expected nominal return from domestic risk-free bonds is equal to the expected nominal return from foreign risk-free bonds expressed in terms of the domestic currency; we can derive the condition for international risk sharing. Under this condition, consumption risk is perfectly allocated (shared) between domestic and foreign households by equating the domestic consumption Euler equation to the foreign counterpart, as follows:

$$\beta E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\eta} \left(\frac{P_t}{P_{t+1}} \right) \right] = \beta E_t \left[\left(\frac{C^*_{t+1}}{C^*_t} \right)^{-\eta} \left(\frac{S_t P^*_t}{S_{t+1} P^*_{t+1}} \right) \right] \tag{3.61}$$

The iterative solution to 3.61 as in Gali & Monacelli (2005) results in the following:

$$C_t = \varGamma Q_t^{\frac{1}{\eta}} C^*_t \tag{3.62}$$

where $\varGamma$ is a constant representing the initial assets position, Q_t is the real exchange rate, C_t is domestic consumption and C^*_t is foreign consumption. When log-linearized, it yields:

$$\tilde{c}_t = \frac{1}{\eta} \tilde{q}_t + \tilde{c}^*_t \tag{3.63}$$

With the assumption of complete international markets, the condition for the uncovered interest rate parity (UIP) can be derived as follows:

$$E_t \xi_{t+1} \left(R_t - R^*_t \frac{S_{t+1}}{S_t} \right) = 0 \tag{3.64}$$

where ξ_{t+1} is the stochastic discount factor, R_t is the domestic interest rate and R^*_t is the foreign interest rate. The log-linear version is as follows:

$$\tilde{r}_t - \tilde{r}^*_t = E_t \varDelta \tilde{s}_{t+1} \tag{3.65}$$

The UIP condition depicts the relationship between expected variation in nominal exchange rates and differential in interest rates in the domestic and foreign economy. The expression indicates that movements in the nominal exchange rate is linked to the gap (wedge) between domestic and foreign nominal interest rates. When we combine the log-linearized UIP condition in 3.65 with the real exchange rate, we obtain the following:

$$E_t \varDelta \tilde{q}_{t+1} = (\tilde{r}^* + E_t \tilde{\pi}^*_{t+1}) - (\tilde{r}_t + E_t \tilde{\pi}_{t+1}) \tag{3.66}$$

This shows that movements in the nominal exchange rate is accounted for by the wedge between domestic and foreign nominal interest rate and inflation.

3.2.8 Monetary Policy

To close the model, monetary policy is captured as central bank's policy reaction function; a Taylor (1993)-type interest rate feedback rule. The Taylor rule is a prescription for how a central bank should set monetary policy rate to promote healthy macroeconomic conditions. In keeping with this tradition, we employ an interest rate rule with which the central bank is assumed to act or respond to stabilize output, inflation and the exchange rate. The rule is notable in the literature for the merits it hold for monetary policy modeling. Clarida *et al.* (2000) and Lubik & Schorfheide (2007) believe the rule summarizes well monetary policy patterns and behaviour in many policy environments. Also, Clarida *et al.* (1999) and Woodford (2003) attest to the general robustness and consistency of the rules with the fundamental principles of optimal monetary policy. It would appear that at the moment, there is a general consensus both in the literature and in policy environments that stabilizing inflation around a particular target and output around its trend should constitute the fundamental goals of monetary policy. Such a policy framework is popularly known as flexible inflation targeting and it fits the Taylor rule setup. The flexibility of the Taylor rule makes it possible to nest a rich set of alternative monetary policy frameworks, especially in many developing and emerging market economies where different monetary policy regimes may be in vogue at different times (Senbeta, 2011). From a modeling stand point, Clarida *et al.* (1999) submits that Taylor rules are known to provide equilibrium determinacy, a requirement for achieving a unique stationary equilibrium solution in rational expectations models. It must be added that, Taylor's prescription that the asymptotic response of the policy rate to inflation must be higher than unity is required for achieving model stability.

3.2.8.1 Generalized Taylor Rule

We adopt a generalized Taylor rule in which the central bank manipulates the nominal interest rate in response to deviations of output, inflation and exchange rate from their steady-state values[10] This is in the spirit of Senbeta (2011) and Hove *et al.*, 2015 as follows:

$$R_t = R_{t-1}^{\rho_r} \left[\left(\frac{Y_t}{\bar{Y}} \right)^{\varpi_1} \left(\frac{\pi_t}{\bar{\pi}} \right)^{\varpi_2} \left(\frac{\pi_t^h}{\bar{\pi}^h} \right)^{\varpi_3} \left(\frac{S_t / S_{t-1}}{\bar{S}} \right)^{\varpi_4} \right]^{1-\rho_r} \tag{3.67}$$

[10] As shown in the log-linear version in 3.68.

The log-linear expression for the above generalized monetary policy rule is as follows:

$$\tilde{r}_t = \rho_r \tilde{r}_{t-1} + (1 - \rho_r) \left(\varpi_1 \tilde{y}_t + \varpi_2 \tilde{\pi}_t + \varpi_3 \tilde{\pi}_t^h + \varpi_4 \Delta \tilde{s}_t \right) + \epsilon_t^r \tag{3.68}$$

Where ϖ_1, ϖ_2, ϖ_3 and ϖ_4 are weights attached by the monetary authority to output, CPI inflation, non-tradable inflation and movement in the exchange rate, respectively. Each weight indicate the importance of their respective coefficient variables in the central bank policy reaction function. The term ρ_r is the smoothing parameter, which captures history dependency of policy in the model (Woodford, 2003). Empirical results have shown that monetary policy innovations rarely radically depart from recent history, rather interest rate changes often reflect a sequence of small adjustments in the same direction (Clarida *et al.*, 2000). In addition, Sack & Wieland (2000) maintains that concerns about model parameter uncertainty and financial system stability concerns makes interest rate smoothing appealing to central banks. It ensures that monetary policy innovations do not become disruptive, surprise the markets unnecessarily and elicit unintended macroeconomic volatility. ϵ_t^r is the monetary policy shock, which accommodates the triggers for monetary policy action.

3.2.8.2 Alternative Monetary Policy Rules

From the generalized Taylor rule in 3.68, we assume the following three alternative policy regimes or strategies which inform the set of policy objectives being targeted by the central bank:

$$\tilde{r}_t = \rho_r \tilde{r}_{t-1} + (1 - \rho_r) \left(\varpi_1 \tilde{y}_t + \varpi_2 \tilde{\pi}_t \right) + \epsilon_t^r \tag{3.69}$$

$$\tilde{r}_t = \rho_r \tilde{r}_{t-1} + (1 - \rho_r) \left(\varpi_1 \tilde{y}_t + \varpi_3 \tilde{\pi}_t^h \right) + \epsilon_t^r \tag{3.70}$$

$$\tilde{r}_t = \rho_r \tilde{r}_{t-1} + (1 - \rho_r) \left(\varpi_1 \tilde{y}_t + \varpi_4 \Delta \tilde{s}_t \right) + \epsilon_t^r \tag{3.71}$$

Equations 3.69, 3.70 and 3.71 are the CPI inflation targeting regime, non-tradable inflation targeting regime and the nominal exchange rate targeting regime, respectively. Under all the three frameworks, the monetary authority is assumed to be interested in employment level, as such it observes the behaviour of aggregate output under all of the alternative monetary policy rules. The significance of output in the Taylor rule is well recognized by Galí (2015) who argues that even "inflation targeters" do not claim to be seeking to stabilize inflation all the time without due consideration for how that would impact real variables like output and employment. The inclusion of the exchange rate in the central bank feedback rule does not necessarily mean that the central bank explicitly pegs the exchange rate, rather it indicates that significant volatility in the exchange rate could elicit a policy response from the monetary authority.

3.2.9 Equilibrium Conditions and Aggregate Resource Constraints

In equilibrium, the demand and supply for tradable goods, non-tradable goods and labour must attain parity. For the goods market, the clearing conditions is such that sum of demand for non-tradable output and oil output (export) must be equal to total domestic production, and can be represented as:

$$Y_t = Y_t^h + Y_t^o \tag{3.72}$$

Where $Y_t^h = C_t^h$ and $Y_t^o = C_t^o$. In log-linear term, equation (72) becomes:

$$\tilde{y} = \tilde{y}_t^h \left(\frac{\bar{Y_t}^h}{\bar{Y_t}}\right) + \tilde{y}_t^o \left(\frac{\bar{Y_t}^o}{\bar{Y_t}}\right) \tag{3.73}$$

Where $\frac{\bar{Y_t}^h}{\bar{Y_t}}$ and $\frac{\bar{Y_t}^o}{\bar{Y_t}}$ are the steady state ratios for non-tradable and tradable output, respectively. These ratios are calibrated based on data and related literature.

3.2.9.1 Demand Side in the goods market

Given that $Y_t^h = C_t^h$, we can substitute 3.11 into C_t^h in 3.7 to derive:

$$Y_t^h = \Psi \left(\frac{P_t^h}{P_t^{f*}} S_t\right)^{-\upsilon(1-\Psi)} C_t \tag{3.74}$$

The log-linear version of 3.74, given below, is the equation depicting the equilibrium condition for the non-tradable goods sector.

$$\tilde{y}_t^h = -\upsilon(1-\Psi)\left(\tilde{p}_t^h + s_t - \tilde{p}_t^{f*}\right) + \tilde{c}_t \tag{3.75}$$

Similarly, given that $Y_t^o = Y_t^{o*} = C_t^o$ in the oil sector and using the equation for the demand for oil (export), we can express oil consumption as follows:

$$Y_t^o = \left(\frac{1-\zeta^*}{\zeta^*}\right)^{\zeta^*} Y_t^{f*} \left(\frac{P_t^{o*}}{P_t^{I*}}\right)^{\zeta^*} \tag{3.76}$$

Log-linearizing equation 3.76 yields:

$$\tilde{y}_t^o = \tilde{y}_t^{f*} + \zeta^* \left(\tilde{p}_t^{o*} - \tilde{p}_t^{I*}\right) \tag{3.77}$$

Equation 3.77 is the equilibrium condition in the oil sector, with the parameter ζ^* being the share of exported oil in the foreign economy's production.

Having derived the two equilibrium conditions that matter in the goods market, we can combine 3.75 and 3.77 with the steady state ratios of the non-tradable and oil sectors to total income to obtain the equilibrium expression that reflect the domestic economy's IS equation as follows;

$$\tilde{y}_t = \left(\frac{\bar{Y}_t^h}{\bar{Y}_t}\right)\left[-\upsilon(1-\Psi)\left(\tilde{p}_t^h + s_t - \tilde{p}_t^{f*}\right) + \tilde{c}_t\right] + \left(\frac{\bar{Y}_t^o}{\bar{Y}_t}\right)\left[\tilde{y}_t^{f*} + \zeta^*\left(\tilde{p}_t^{o*} - \tilde{p}_t^{I*}\right)\right] \tag{3.78}$$

3.2.9.2 Supply Side in the Goods market

The supply side of the equilibrium dynamics can be obtained using the derived marginal costs in the oil and non-tradable sectors. The marginal cost in the oil sector is given as:

$$r\tilde{m}c_t^o = \tilde{w}_t - \tilde{z}_t^o - \tilde{p}_t^o \tag{3.79}$$

Substituting $\tilde{w}_t$ from 3.20, $\tilde{p}_t$ from 3.12, $\tilde{p}_t^f$ from 3.37 and $\tilde{p}_t^o$ from 3.55; we obtain the equilibrium real marginal cost in the oil sector as follows:

$$r\tilde{m}c_t^o = \eta\tilde{c}_t + \varrho\tilde{l}_t + (1-\Psi)\left(\tilde{p}_t^{f*} - \tilde{s}_t\right) + \Psi\tilde{p}_t^h - \tilde{p}_t^{o*} + \tilde{s}_t - \tilde{z}_t^o \tag{3.80}$$

Similarly, the real marginal cost in the non-tradable sector is given as:

$$r\tilde{m}c_t^h = \tilde{w}_t - \tilde{z}_t^h - \tilde{p}_t^h \tag{3.81}$$

Substituting $\tilde{w}_t$ from 3.20, $\tilde{p}_t$ from 3.12 and $\tilde{p}_t^f$ from 3.37; we obtain the equilibrium real marginal cost in the non-tradable sector as follows:

$$r\tilde{m}c_t^h = \eta\tilde{c}_t + \varrho\tilde{l}_t + (1-\Psi)\left(\tilde{p}_t^{f*} - \tilde{s}_t\right) + \Psi\tilde{p}_t^h - \tilde{p}_t^h - \tilde{z}_t^h \tag{3.82}$$

3.2.9.3 Labour Market

The clearing condition for the labour market is such that the sum of employment in the oil and non-tradable sectors must be equal to the total labour supply in the economy. It is represented as follows:

$$L_t = L_t^o + L_t^h \tag{3.83}$$

We derive the equilibrium dynamics in the labour market by log-linearizing 3.83, and substituting out the log-linear versions of 3.22 and 3.28 in same; together with the corresponding steady state ratios as follows:

$$\tilde{l}_t = \left(\frac{\bar{L}^o}{\bar{L}}\right)(\tilde{y}_t^o - \tilde{z}_t^o) + \left(\frac{\bar{L}^h}{\bar{L}}\right)(\tilde{y}_t^h - \tilde{z}_t^h) \tag{3.84}$$

Where $\frac{\bar{L}^o}{\bar{L}}$ and $\frac{\bar{L}^h}{\bar{L}}$ are the steady state share of employment in the oil and non-traded sectors, respectively.

3.2.10 Equilibrium Conditions in the Foreign Economy

The log-linear equilibrium conditions for foreign consumption, foreign non-tradable consumption and foreign tradable consumption:

$$\tilde{y}_t^* = \Psi^* \tilde{y}_t^{h*} + (1 - \Psi^*)\, \tilde{y}_t^{f*} \tag{3.85}$$

$$\tilde{y}_t^{h*} = -\upsilon^* \tilde{p}_t^{h*} + \upsilon^* \left(\Psi^* \tilde{p}_t^{h*} + (1 - \Psi^*)\, \tilde{p}_t^{f*}\right) + y_t^* \tag{3.86}$$

$$\tilde{y}_t^{f*} = \zeta^* \tilde{y}_t^o + (1 - \zeta^*)\, \tilde{y}_t^{I*} \tag{3.87}$$

Other equations characterizing the foreign economy include the exogenous process of foreign interest rate, foreign oil price and inflation, as well as foreign intermediate goods price and inflation:

$$\tilde{r}_t^* = \rho_{r*} \tilde{r}_{t-1}^* + \epsilon_t^{r*} \tag{3.88}$$

$$\tilde{p}_t^{o*} = \rho_{p^{o*}} \tilde{p}_{t-1}^{o*} + \epsilon_t^{p^{o*}} \tag{3.89}$$

$$\tilde{\pi}_t^{o*} = \rho_{\pi^{o*}} \tilde{\pi}_{t-1}^{o*} + \epsilon_t^{\pi^{o*}} \tag{3.90}$$

$$\tilde{p}_t^{I*} = \rho_{p^{I*}} \tilde{p}_{t-1}^{I*} + \epsilon_t^{p^{I*}} \tag{3.91}$$

$$\tilde{\pi}_t^{I*} = \rho_{\pi^{I*}} \tilde{\pi}_{t-1}^{I*} + \epsilon_t^{\pi^{I*}} \tag{3.92}$$

Ultimately, the model's competitive equilibrium system is the aggregation of the optimal solutions to (a) household's problem $\tilde{c}_t(i)$, $\tilde{l}_t(i)$; (b) firm's problem $\tilde{y}_t(i)$, $\tilde{y}_t^h(i)$, $\tilde{y}_t^o(i)$; and (c) pricing decisions and price indices $\tilde{p}_t(i)$, $\tilde{p}_t^h(i)$, $\tilde{p}_t^f(i)$, $\tilde{\pi}_t(i)$, $\tilde{\pi}_t^h(i)$, $\tilde{\pi}_t^f(i)$, all market clearing conditions, monetary policy rules, interest rate parity condition and the exogenous shock processes. The remaining model's equilibrium characterizing sequences which yield the solution for the oil exporting small open and the foreign economies are: $\tilde{s}_t$, $\tilde{q}_t$, $r\tilde{m}c_t^o$, $r\tilde{m}c_t^h$, $\tilde{r}_t$, $\tilde{z}_t^o$, $\tilde{z}_t^h$, $\tilde{r}_t^*$, $\tilde{y}_t^*$, $\tilde{y}_t^{h*}$, $\tilde{y}_t^{f*}$, $\tilde{p}_t^{o*}$, $\tilde{\pi}_t^{o*}$, $\tilde{p}_t^{I*}$, $\tilde{\pi}_t^{I*}$, $\tilde{p}_t^{h*}$, $\tilde{p}_t^{f*}$, $\tilde{\pi}_t^{f*}$, $\tilde{z}_t^{h*}$ and $\tilde{z}_t^{I*}$.

3.3 Parameter Calibration, Model Solution and Simulation

To analyze the impact of a positive oil price shock, the model's structural parameters are calibrated to match the general features of small open economies exporting primary products and to reflect specific characteristics of the Nigerian economy. In doing this, we rely heavily on the wider small open economy literature, the limited literature on Nigeria and comparable emerging and developing economies business cycle characteristics and data driven estimates from time series analysis. The key ratios are obtained using data sourced from the IMF, the World Bank and the Central Bank of Nigeria. The subjective discount factor β is set at 0.99 implying that steady state real interest is in the neighbourhood of 4% annually. The inverse of the elasticity of inter-temporal substitution, being the risk aversion parameter η is calibrated as 1, in line with the estimate obtained by Steinbach *et al.* (2009) for South Africa, a commodity exporter. The elasticity of the marginal dis-utility of labour ϱ is set at 6 following estimate from Alpanda *et al.* (2010). The share of non-traded goods in total domestic consumption, Ψ and the share of imports in total domestic consumption, otherwise known as the degree of openness, $1 - \Psi$ are estimated at 0.8 and 0.2, respectively. The estimate is based on the average import to GDP ratio for Nigeria between 1981 and 2015. For the foreign economy, in line with the earlier assumption of consumption symmetry between domestic and foreign households, the share of non-tradable goods in total consumption is given as 0.8.

We follow Santacreu (2005) and Alpanda *et al.* (2010) in setting the persistence of the productivity variables in the oil ρ_{z^o} and non-oil ρ_{z^h} sectors to 0.85 and 0.74, respectively; and the foreign intermediate and non-traded goods sectors both have productivity variables ($\rho_{z^{I*}}$ and $\rho_{z^{h*}}$) persistence of 0.8. The persistence parameters for foreign interest rate ρ_{r*}, foreign oil price $\rho_{p^{o*}}$, foreign oil inflation $\rho_{\pi^{o*}}$, foreign intermediate goods price $\rho_{p^{I*}}$, and the foreign intermediate goods inflation $\rho_{\pi^{I*}}$ are set at 0.8, 0.8, 0.5, and 0.5, respectively; while the share of oil in foreign production ζ^* is calibrated at 0.26 in the spirit of Hove *et al.* (2015).

The probability that firms are unable to re-optimize every period, otherwise referred to as the stickiness or nominal price rigidity parameter is given as 0.75 in line with Christiano *et al.* (2005) and Gali & Monacelli (2005); suggesting that price adjustment is achieved averagely once in every four (4) quarters. The smoothing parameter ρ_r for the Taylor rule, following Ortiz & Sturzenegger (2007), is set at 0.73. The role of the parameter is to offer some assurance to economic agents on the trajectory of monetary policy stance and to anchor expectations about the evolution of interest rate in the economy. The monetary policy parameters in the Taylor rule ϖ_1, ϖ_2, ϖ_3 and ϖ_4 are fixed at 0.5, 1.5, 1.5 and 0.25; respectively. The type of Taylor rules that incorporate exchange rate element is in the category of the modified Taylor rules common with small open, emerging markets and developing economies. The modification of the traditional Taylor rule to account explicitly for the exchange rate in setting monetary policy instrument is consistent with an inflation targeting monetary policy framework (Mishkin, 2007). Generally, in many inflation targeting regimes, especially the class being modeled here, stabilization of output and exchange rate in addition to inflation are accommodated in the monetary policy reaction function. Weights assigned to CPI and domestic inflation satisfies the Taylor principle, which recommends an aggressive stance to inflation; while values assigned to output and exchange rate are consistent with those employed by Steinbach *et al.* (2009) and Zeufack *et al.* (2016). The coefficient of real marginal cost ($\kappa_t^h = \frac{(1-\beta\theta^h)(1-\theta^h)}{\theta^h}$) in the new Keynesian Philips curve equation is obtained as 0.0825; while the elasticity of substitution within each goods category (i.e. non-tradable and imports) and between the two goods categories are set at 10 and 1, respectively, corresponding to values in Romero (2008) and Hove *et al.* (2015). Using the macroeconomic fundamentals of Nigeria and data sourced from the IMF IFS and the Nigerian Bureau of Statistics (NBS) and the Central Bank of Nigeria (CBN), we obtain the steady state ratios for non-tradable output to total income $\frac{\bar{Y_t}^h}{\bar{Y_t}}$, oil output (exports) to total income $\frac{\bar{Y_t}^o}{\bar{Y_t}}$, non-tradable sector employment to total employment $\frac{\bar{L}^h}{\bar{L}}$ and oil sector employment to total employment $\frac{\bar{L}^o}{\bar{L}}$ as 0.75, 0.25, 0.65 and 0.35; respectively.

We solve the model in Dynare after deriving the first order conditions of all optimizing agents, the equilibrium conditions and specifying the shock processes. The Dynare software in Matlab environment utilizes the Blanchard & Khan (1980) procedure to derive model solutions. We proceed to simulate the model to examine how a positive shock to the oil price affects key macroeconomic variables in the economy.

3.4 Results

We apply a ten percent positive standard deviation shock to the international price of oil and observe the impulse responses of selected macroeconomic variables under the three alternative monetary policy frameworks. Our objective is to unravel the transmission mechanism of oil price shocks in the oil exporting small open economy given (i) CPI inflation targeting policy rule (CITR); (ii) domestic inflation targeting policy rule (DITR); and (iii) exchange rate targeting policy rule (ERTR). The response of each macroeconomic variable to a positive oil price shock and the paths through which the shock permeates the economy under each monetary policy environment will provide useful insights on model dynamics. In addition, through the analysis, we can identify the monetary policy rule associated with pronounced volatility in selected macroeconomic variables given oil price shock. Therefore, each monetary policy rule's merit will derive from the level of macroeconomic fluctuations elicited by oil price shock under it.

Figure 3.2 below shows the impulse responses of shock to oil price under the three alternative policy rules.

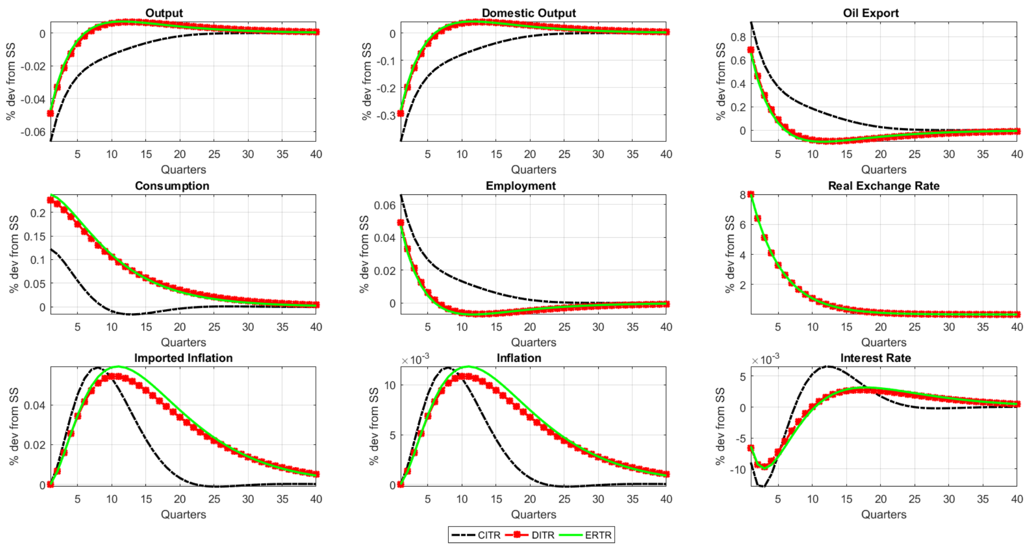

Figure 3.2: Responses to a positive oil price shock under alternative Monetary Policy Regimes

3.4.1 Oil Price Shocks and Macroeconomic Responses

An oil price shock is shown to increase the value of oil exports on impact. Exogenous increase in oil price decreases oil sector real marginal cost and raises oil supply, resulting in higher oil exports and output. The oil sector exhibits significant sensitivity to oil price movements. The monetary policy rule that targets the consumer price index (CITR) elicits the largest oil sector response to the positive oil price shock. Although, the domestic inflation targeting regime (DITR) and the exchange rate targeting regime (ERTR) provide nearly the same magnitude of oil output response to the positive shock to oil price, the CITR clearly outperforms them. In addition, oil price shock effects on oil output under DITR and ERTR is more volatile given that the initial increase in oil output turned into a decline by the sixth quarter before becoming fully dissipated with that of the CITR in the thirtieth quarter.

Conversely, the non-tradable (domestic) output sector nose-dived in response to a positive oil price shock. Non-oil output declined on impact in response to the positive innovation to oil price under all of the three alternative monetary policy rules. The non-tradable output fall under the CITR is worse than those under the DITR and ERTR. The phenomenon[11] in which boom in the resource sector results in the depression of the domestic non-resource sector as in this case is known as the Dutch disease, a problem to which many developing resource-rich economies are susceptible. In this respect, we find evidence of the operation of the two principal mechanisms of the Dutch disease; viz: the resource movement effect and the wealth/spending effect.

The resource movement effect is associated with the migration of productive (labour) resources from the non-tradable goods sector to the oil sector, where the marginal productivity of labour has risen due to oil boom. The exodus of workers from the non-tradable sector to the oil sector is a causal factor in the decline experienced in the non-tradable sector. Additionally, given the size of the non-tradable sector, it's decline resulted in the overall output slump. However, while the shock elicits decline in both non-tradable and total output, the percentage increase in the oil output is by far higher than the percentage fall in both non-tradable and overall output. This development has important implications for employment and consumption. The booming oil sector, characterized by improved wages attracts workers from the non-traded goods sector and creates new employment opportunities for labour force participants. This results in a rise in total employment. Employment is found to be more responsive to an oil price shock under the CITR compared to both DITR and ERTR that often trail each other.

In the same vein, consumption exhibit a positive response to oil price shock. Given that more people are now in work as a result of the oil windfall, higher marginal productivity of labour in the oil sector will propel higher wages and consequently, higher consumption; allowing the spending effect to manifest through higher demand for consumer goods in the economy. Comparatively, consumption is shown

[11] See Corden (1984), Egert & Leonard (2008), Kalcheva & Oomes (2007), Benkhodja (2014) and Hove *et al.* (2015)

to be more sensitive to oil price shock under ERTR and DITR than the CITR. This implies that consumption growth in response to oil price shock is more contained and less volatile under a monetary policy rule that targets the composite measure of inflation. Furthermore, we can infer that the consequent increase in consumption is oriented towards imported goods, given that exchange rate appreciation will make imported goods more attractive to domestic consumers and the effects of the Dutch disease can not allow the domestic non-tradable sector to respond immediately to higher demand. Consumption stabilization is better attained under the CITR compared with under both ERTR and DITR, under which consumption response to an oil price shock is more amplified. Given the circumstances of the Dutch disease and real exchange rate appreciation, higher consumption in response to oil price shocks under ERTR and DITR may build external account vulnerabilities which could undermine the economy's current account and balance of payments position. A situation where output falls, yet consumption rises as exchange rate appreciation encourages higher imports bills which may precipitate a range of external sector problems such as loss of domestic competitiveness, unsustainable import bills, high imported inflation, external reserves pressure and a potential currency crisis if oil market conditions reverses.

Oil price shock results in the appreciation of the real exchange rate. This is attributable to the consequent rise in oil sales receipts or foreign exchange. Combined with the wealth effect, real exchange rate appreciation provide domestic consumers with an additional incentive to consume more imported goods. Whenever, the real exchange rate appreciates, the relative price of imports fall and domestic consumers consume more. In any case, the non-tradable sector is already on the decline and can not adjust to the improved domestic demand propelled by the oil boom. Oil price shock produced the same high magnitude of exchange rate appreciation under the three (3) policy rules; suggesting that oil earnings play a very critical role in the real exchange rate determination process in developing oil exporting small open economies. It does not matter, what inflation targeting regime is in vogue, an oil price shock would elicit a similar response in the real exchange rate of a less-developed economy that exports oil.

The effect of oil price shock on inflation is not manifest on impact, however, it shows that a positive inflation expectation exist and that actual inflation may rise in the medium-to-long term. Therefore, the concern about inflation is palpable amongst domestic economic agents and the principal source of the inflation expectations is the price index of imported goods. Whereas, inflation tend to be more responsive and volatile under the CITR, it is more persistent under the DITR and ERTR.

3.4.2 Oil Price Shock, Dutch Disease and Monetary Policy Response

Given that there is no immediate threat of inflation the central bank has no incentive to tighten the stance of policy. Conversely, the effect of the Dutch disease on the non-tradable output sector compels the central bank to lower the interest rate. The significant decline in non-tradable output which accounts for the marginal decline in the economy's overall output leads to an interest rate cut, given that the central bank's reaction function envisages output performance as an objective in the Taylor rule. Mishkin (2007) notes that central banks focus on output stabilization enjoys two main merits. The first is in connection with conclusions from the canonical aggregate supply models of Svensson (1997) and Clarida *et al.* (1999) which indicates that variation in inflation is influenced by output gap; and the second is that the general public also care about the trade-off between output and inflation fluctuations. Output volatility is important for the setting of monetary policy because it affects the forecast of future inflation and has implications for welfare.

The central bank, therefore, is compelled to act through an accommodatory monetary policy to arrest the negative deviation of output from steady state. Moreover, the real exchange rate appreciation occasioned by the oil price shock may provide an additional impetus for the central bank to ease monetary policy with the intent to re-inflate the non-tradable sector and boost overall output. Interest rate cut is sharper under the CITR, the normalization of monetary policy through rate hike is also sharper under the CITR, with interest rate response dissipating faster than under the alternative policy rules. Under both DITR and ERTR however, the cut in interest rate was benign, policy normalization was slower and policy response took a longer time to dissipate. On the whole, the point where policy normalization (interest rate response climbed to positive territory) began are shown to co-incide with the points where both imported and CPI inflation inflation pressures became manifest and at these points, output decline had dissipated, especially under the DITR and ERTR. These interactions tend to indicate the central bank's readiness to contain inflation aggressively whenever the threat emerges.

3.4.3 Volatility under alternative Monetary Policy Rules

The standard deviations or volatility associated with each of the selected macroeconomic variables under the three alternative monetary policy rules in focus are presented in table 3.1 below. In the table, the real exchange rate is shown to exhibit the highest volatility and is the same under the three policy regimes. This confirms the results of the impulse response function which shows real exchange rate as the variable with the most significant response to oil price shock under all the policy rules. The real exchange rate is revealed as the conveyor of external shocks, especially with a high sensitivity to terms of trade fluctuations. The real exchange rate volatility is evident under all three monetary policy specifications. In line with Friedman (1953) and Mundell (1961), the exchange rate is believed to act as a shock absorber and a cushion for the economy in the face of external shocks, such as oil price shocks. External shocks often hit the real exchange rate in small open economies first, before they are transmitted to the domestic economy. The real exchange rate comes under intense pressure to either appreciate or depreciate depending on the nature of the shock. Hence, its high levels of volatility across the alternative monetary policy setups. However, the conveyor role of the exchange rate works in flexible exchange rate environments and would not matter in a peg, except in the informal sector where multiple exchange rates may result. In the event of an external shock, flexible exchange rate system allows for swift changes in relative prices, which minimizes the impact of the shock on output and employment (Maliszewska & Maliszewski, 2003).

Exported oil output exhibits the second largest volatility across all three policy frameworks; with CITR having the largest volatility, followed by DITR and ERTR, respectively. The high oil output volatility tend to reflect the inverse relationship between oil price and the marginal cost in the oil sector. Higher oil price lowers oil sector marginal cost and thus elicits considerable responses that increases exported oil output. As is the case in many commodity exporters, the commodity sector output often mimic the evolution of the international price of the commodity, and by the same token, oil price volatility tend to drive oil export volatility. Comparatively, the least volatility under the ERTR suggest that targeting exchange rate can moderate volatility in the oil sector, given that the exchange rate is the prime channel for external shocks transmission in a commodity exporting small open economy.

Variables/Policy Rules	**CITR**	**DITR**	**ERTR**
Output	0.1108	0.0686	0.0647
Non-tradable Output	0.6649	0.4115	0.3883
Exported (Oil) Output	1.5515	0.9602	0.9060
Consumption	0.2197	0.5845	0.6132
Employment	0.1108	0.0686	0.0647
Real Exchange Rate	13.3333	13.3333	13.3333
Imported Inflation	0.1636	0.2031	0.2197
Inflation	0.0327	0.0406	0.0439
Interest Rate	0.0300	0.0225	0.0241

Table 3.1: Standard Deviation under the alternative policy rules

Output and non-tradable output are shown to be most volatile under the CITR, in line with results from the impulse response functions and reflecting effects of volatility from the imported and non-tradable components of the composite inflation index. Clearly, the CITR provides the best monetary policy environment to minimize consumption volatility, as its value under the rule is less than half of the volatility under both DITR and ERTR. This tend to align with results from Devereux *et al.* (2006), where it is established that targeting the CPI inflation leads to minimum consumption volatility. To obtain the least volatility in the imported inflation and aggregate inflation, the CITR provides the best guarantee as volatility of consumption is least under the CITR.

The lowest volatility is associated with the interest rate. Two reasons may have accounted for this. First is the possible manifestation of monetary policy inertia, which is a deliberate effort to achieve interest rate smoothing by the central bank Woodford (1999). It would seem that interest rate smoothing may be re-inforced where there is no immediate threat to price stability in the economy. Second, from the results of impulse response functions, a positive shock to oil price did not elicit an immediate inflationary uptick, therefore, the expected aggressive interest rate response to inflation could not materialize as inflation expectations were constrained to medium term horizon and no current inflation threat resulted from the oil price shock. As discussed earlier, central bank's response was however intended to address the effect of Dutch disease in the non-tradable sector. Interest rate volatility is most significant under CITR, showing that the rule aggressively employs interest rate to keep the economy on a particular business cycle path. This shows that the monetary authority would react most aggressively to oil price shocks under a composite inflation index.

3.5 Optimal Monetary Policy and Welfare Evaluation

The literature presents two alternative routes through which a welfare loss function can be derived; either through the fundamentals obtained from the representative household utility function as in Rotemberg & Woodford (1999), Woodford (2003), and Galí (2008, 2015) or through a somewhat ad-hoc approach which in the spirit of Clarida *et al.* (1999) and Alpanda *et al.* (2010) assumes a central bank's loss function seeking to minimize the deviations of inflation and output from their target levels. In the first instance, Woodford (2003) demonstrates the possibility of motivating a quadratic loss function as a second order Taylor approximation of the expected utility of a representative household, which equates the expected discounted sum of period losses for specific coefficients. In this way, a linear approximation to the policy function is shown to be sufficient to approximate welfare up to a second order, provided such a second order approximation to the welfare function has quadratic terms. The resulting welfare loss will be proportional to the expected discounted sum of squared deviations of variables. In the second instance, following from the effects of the welfare-reducing distortions embedded in the new Keynesian model, it is assumed that the central bank dislikes inflation and output gap. Thus, the central bank welfare is characterized as a present discounted value of a quadratic loss function in inflation and output gap.

3.5.1 Utility-based Welfare Loss function

In Woodford (2003) and Galí (2008), the expected welfare loss function was derived as a fraction of steady state consumption level of a representative consumer as follows:

$$L = -E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{U_t - U}{U_c C} \right) = E_0 \sum_{t=0}^{\infty} \beta^t L_t^p \tag{3.93}$$

where U_t is the utility at time t, U is the steady state utility and C is the steady state consumption; while L_t^p represents the loss per period and it is given as:

$$L_t^p = \lambda_\pi \pi_t^2 + \lambda_y y_t^2 \tag{3.94}$$

where λ_π and λ_y are constants defined essentially by model parameters. In this first approach that features optimizing agents, whose utility depends on consumption and hours of work, and sticky prices, expected welfare is believed to decline with the squared deviation of inflation from optimal rate (a zero inflation level) and the squared deviation of output from the natural output level.

If prices are sticky, fluctuation in output gap implies that the average mark-up over marginal cost will be unstable. This may result in labour utilization inefficiency in the production process, thus leading to a sub-optimal employment level. This provides a justification for stabilizing the output gap to promote the stability of the average mark-up. Similarly, as argued by Woodford (2003), the situation of price stickiness exploited by firms that can re-optimize will yield a non-zero inflation rate. The resulting relative price distortions will produce dead weight losses because of a sub-optimal production setup. For instance, a positive inflation will compel firms that are stuck with the old price (because they unable to re-optimize for reasons discussed in the New Keynesian literature for price stickiness) to sell at a price below their competitors and produce in excess of the quantity that makes for an efficient allocation. It is believed that if prices were to be perfectly stable, there would be no incentives for firms with the leverage to raise prices and the situation will be similar to that of perfect price flexibility. Galí (2015) notes that following assumptions of the Real Business Cycle literature, the attainment of price stability implies efficiency in output and vice versa, in line with the principle of divine co-incidence. Divine co-incidence implies that the monetary authority need not worry about what constitute the efficient output level per period, given that it can be achieved automatically as a by-product of the policy that ensures price stabilization.

The inclusion of the interest rate in the loss function has a micro-founded motivation as well. Woodford (2003) provides a derivation in which the squared deviation of interest rate from its steady state value features in the period loss when transactions frictions are taken into cognizance and real money balances appear in the utility function. Levin *et al.* (1999) and Williams (2003) imposes a constraint on interest rate variability on the grounds that: (i) a highly volatile short term interest rate could result in higher long-term interest rate due to higher term premium; (ii) leaving out interest rate in the loss function could make optimal monetary policy to be extremely aggressive to a point where the nominal interest rates hits the zero-lower bound. Levin & Williams (2003), Orphanides & Williams (2008) and Ilbas (2012) reason that, since policymakers are more concerned about the inter-temporal variation in interest rate, it would be appropriate to replace i_t with $\triangle i_t$ in the loss function.

In relation to the open economy framework where the exchange rate and/or the terms of trade may have implications for welfare, Galí (2015) maintains that the central bank has an incentive to influence or respond to the terms of trade in the interest of domestic households. Clarida *et al.* (2001) submits that the open economy loss function is not different from the one for the closed economy if there is complete pass-through of real exchange rate fluctuations to the domestic economy and the domestic inflation. On the other hand, Corsetti *et al.* (2010) provides allowance for incomplete pass-through and argues that the law of one price gap should be included in the loss function.

The standard new Keynesian model for the closed economy can be distinguished from the open economy version, generally, by the introduction of additional layers of frictions emanating from rigidities such as those associated with nominal import price, imperfect risk-sharing, financial frictions and exogenous shocks of foreign origins. Consequently, the central bank in an open economy is conditioned to respond to extra distortions that may undermine key objects of monetary policy.

3.5.2 Ad-hoc (central bank) Welfare Loss Function

In this approach, the central bank is assumed to dislike inflation and also believed to be concerned about the deviation of output from the optimal equilibrium level. Therefore, the welfare of the central bank is assumed to approximate the discounted quadratic loss function in inflation and output gap. In an ad-hoc approach, the central bank will seek to minimize a loss function of the form:

$$min \qquad \frac{1}{2}E_0\left(\sum_{t=0}^{\infty}\beta^t(\tilde{\pi}_t^2+\omega\tilde{y}_t^2)\right) \tag{3.95}$$

where $\tilde{y}_t$ is the output gap and ω is the relative weight attached to output gap by the central bank. The central bank chooses inflation and output gap, given its choice of the nominal interest rate (i) which in turn determines the real interest rate (r) subject to the given path of $E_t\pi_{t+1}$, the term for expected inflation in the Philip's curve. Therefore, the central bank's loss function will be minimized subject to the Philip's curve constraint. Where markup shocks are real, the central bank wanting to achieve inflation and output stabilization will be constrained by Philip's curve (Davig, 2007).

We employ a loss function of the ad-hoc type with some extensions to accommodate small open economy considerations. This approach follows the literature on monetary policy and aligns with Clarida *et al.* (1999) and Laxton & Pesenti (2003) and follows from the assumption that the central bank has a fundamental objective of minimizing the variance of output and inflation from their target values. We consider a loss function which nest the realization of central bank's objective on policy targets into an aggregate measure of welfare in the economy. The intent of the monetary authority therefore is to reduce or eliminate welfare losses arising from deviations of inflation, output, interest rates and exchange rates from their steady state values.

The ad-hoc loss function, in contrast to those derived from micro-founded fundamentals, are popular in the literature for a number of reasons. First, they allow for the incorporation of a smoothing parameter for interest rate in the model. The interest rate smoothing parameter reflects monetary policy inertia for which evidence is found in the data. Second, there are concerns that models used in the utility-based loss function may not be sufficiently micro-founded or too complicated to produce a true welfare function (Ilbas *et al.*, 2013). Third, Clarida *et al.* (1999) notes that commonly employed models do not envisage all the costs associated with fluctuations in the economy, thus, making the use of extra-model judgments incumbent when making decisions on policy objectives. Fourth, based on Adolfson *et al.* (2011), observable macroeconomic variables may be used to set up the loss function in order to provide a better guide for welfare analysis, especially in economies characterized by significant business cycle fluctuations. Fifth, central bank loss functions are believed to capture uncertainty induced by inflation variability; and this is considered as the main cost of inflation in the economy (Clarida *et al.*, 1999). Sixth, the optimization framework provided by the loss function is deemed reasonable and simplifies the estimation of welfare. Seventh, the ad-hoc loss function recognizes the fact that parts of the central bank's objectives do have the force of the law, and therefore not within the bank's control. The loss function allow us to characterize central bank's preferences in simple fashion that aligns with the practical implementation or operation of monetary policy. Consequently, we consider the following welfare loss function:

$$L = E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \lambda_\pi \pi_t^2 + \lambda_y y_t^2 + \lambda_s s_t^2 + \lambda_r r_t^2 \right\} \tag{3.96}$$

The loss function in 3.96 shows that central bank intends to minimize losses arising from fluctuations in π_t, the measure of inflation which could either be the CPI or domestic inflation measure; y_t, output; s_t, exchange rate; and r_t, interest rate. The exchange rate is incorporated in the loss function to reflect it's importance to the optimizing policymaker in a small open economy. This process is in line with Gali & Monacelli (2005) and Kirsanova *et al.* (2006) who demonstrates that relaxing parameter restrictions of the utility-based loss function results in a more complex welfare criterion that includes the terms of trade, which can be proxied by the exchange rate. In addition, De Paoli (2009) utilizes a terms of trade externality to elicit the motivation for the inclusion of the real exchange rate in the objective function. As noted earlier, the interest rate smoothing parameter in the loss function indicates the central bank's distaste for huge, sudden and extreme volatility in interest rates. Woodford (2003) also observes that the interest rate element in the loss function helps the central banks to prevent a possibility of hitting the zero lower bound on interest rates. The parameters of the policy rule(s) are selected in an optimal way to minimize the quadratic loss function[12]

As noted by Levin & Williams (2003) and Cateau (2007) weather the policy function is derived from household utility fundamentals or on ad-hoc basis, there is no consensus in the literature on the appropriate size of relevant weights in the loss function. In practice, policymakers rarely select weights based on the theoretical findings of a single model, rather, it takes outputs of a suite of models and expert opinions to assign values to the weight of the loss function.

When the unconditional expectations is applied on 3.96 in line with Rudebusch & Svensson (1999), the loss function becomes:

$$E(L_t) = \lambda_\pi Var(\pi_t) + \lambda_y Var(y_t) + \lambda_r Var(r_t) + \lambda_s Var(s_t) \tag{3.97}$$

The resulting loss function in 3.97 represent the weighted average of the unconditional variances of inflation, output, exchange rate and interest rate. The weights (λ_π, λ_y, λ_s and λ_r) are selected optimally to minimize the quadratic loss function. The smaller the value of the loss function the less the welfare losses. Therefore, the monetary policy rule that results in a minimum value for the loss function is the optimal monetary policy. However, this loss function may be minimized under the optimized simple rules, discretion and commitment policies. Accordingly, the ad-hoc loss function of the modeled central bank minimizes losses arising from the deviations of inflation, output, interest and exchange rates from respective steady state values. Weights assigned to variables in the the loss function is crucial in the loss minimization process. Like Alpanda *et al.* (2010), Ferrero & Seneca (2015) and Hove *et al.* (2015), we construct a set of alternative values of the relative loss function weights ranging from 0.5 to 2; leading to ten (10) alternative plausible weight combinations, with the weight of inflation variance normalized to unity for simplicity and in line with the literature. Each weighted loss function is minimized under each of the alternative simple policy rules to compute the values of central bank losses.

3.5.3 Optimized Simple Rules given 10 percent positive oil price shock

An optimized simple rule is a rule within a category for which relevant parameters are chosen to minimize a loss function. In our case, these are three (3) Taylor-type policy rules in equations 3.69 - 3.71, which features the pair of interest rate smoothing parameter[13] and output deviation from steady state; with the deviations of aggregate inflation, domestic inflation and changes in the nominal exchange rate

[12]Dynare tools for optimal policy are utilized for the computation of the optimal parameters.

[13]Other terms used by Galí (2008) to qualify this term include inertia and history dependence.

from their steady states, respectively. The objective[14] is to optimize the coefficients of the policy rules[15] in order to minimize the variances of the expected loss function in equation 3.97. The first rule responds to output and aggregate inflation, the second to output and domestic inflation and the third to output and exchange rate given a ten (10) percent oil price shock. Additional justification for the inclusion of the exchange rate in the simple monetary policy feedback rule for a small open economy is Ball (1999), who finds that exchange rate's presence enhances the performance of the simple rule significantly and Taylor (2001) and Batini *et al.* (2003) who uncover an effect, albeit minimal.

Table 3.2 below reports the results obtained from optimizing the coefficients of the different monetary policy rules to derive values for the policy maker's loss function. We show ten (10) loss values resulting from the policy maker's range of weights combination for the loss function. Each weights combination reflects relative preference of the central bank for minimizing the variance of the variables in the loss function. The range of the weights is between 0.5 and 2, and the size of the weight attached to individual variables in the loss function is determined by how strongly the policymaker would care about stabilizing the variables. A policymaker that cares strongly about stabilizing a variable, say output, inflation etc; in the loss function will assign a value above 1 or 2 to the variable; otherwise, it would weight such a variable less by assigning 0.5 or 1 to the variable.

Loss values under alternative rules			Preferences (weights)			
CITR	DITR	ERTR	λ_π	λ_y	λ_r	λ_s
0.00095	0.00090	0.00094	1	0.5	0.5	0.5
0.00120	0.00120	0.00120	1	1	0.5	0.5
0.00130	0.00130	0.00130	1	1.5	0.5	0.5
0.00140	0.00140	0.00140	1	2	0.5	0.5
0.00096	0.00091	0.00095	1	0.5	1	0.5
0.00097	0.00092	0.00095	1	0.5	1.5	0.5
0.00098	0.00093	0.00096	1	0.5	2	0.5
0.00140	0.00120	0.00140	1	0.5	0.5	1
0.00170	0.00150	0.00170	1	0.5	0.5	1.5
0.00190	0.00170	0.00190	1	0.5	0.5	2

Table 3.2: Welfare losses under alternative policy rules given a 10% oil price shock

The optimized simple rules (OSR) policy exercise shows that the policy maker's preference with weight values of 1 and 0.5 for inflation and other variables, re-

[14] The Dynare's toolbox which implements the optimized simple rules (OSR) algorithm is used. It numerically searches the parameter space of the policy function to obtain those parameters which minimize the weighted variances of the relevant variables and reports the loss value.

[15] Alternative Taylor Rules. CITR denotes CPI inflation targeting regime, DITR denotes domestic inflation targeting regime; while ERTR denotes exchange rate targeting regime. Each regime feature interest rate inertia and output gap.

spectively; produces the lowest loss values under all three policy rules. Thus, the preference that makes the central bank less tolerant of inflation volatility compared to interest rate, output gap and the exchange rate volatilities is deemed optimal under the CPI targeting, domestic inflation targeting and exchange rate targeting rules. At that central bank's preference of weights selection of inflation (1), output (0.5), interest rate (0.5) and exchange rate (0.5) however, the domestic inflation targeting policy rule (DITR) delivers the least loss value. Seven (7) out of the ten (10) formulated policy preferences (weights combinations) indicates that the DITR will deliver the best outcome for welfare, while the remainder deliver the same results across all three policy reaction functions. It is observed that in the preferences that produced same loss values, the policy tends to be more interested in output stabilization as output weights of 1 - 2 are associated with them. The remaining seven (7) preferences have an output weight of just 0.5. Consequently, the DITR is shown to be the superior, welfare-enhancing monetary policy rule in the class of the optimized simple rules in this model.

Under the alternative preferences, the DITR also delivers the second and third best results in comparison with other rules. These outcomes are associated with the weight combinations that indicates the central bank strongly care about interest rate volatility. Next to the DITR, the ERTR provides the second best welfare outcome; while the CITR yields the least welfare maximizing results. Therefore, the monetary policy rule that targets domestic (non-tradable) inflation is the one with the best welfare-maximizing outcome. This result finds strong support in the literature. For example, Aoki (2001) observes that optimal monetary policy is the one that targets inflation with sticky prices given that it ensures equilibrium in the goods market with the most sticky prices. Kollmann (2002), under a local currency pricing condition and absence of the law of one price, argues that it is optimal to pursue domestic inflation stabilization via a Taylor-type policy rule notwithstanding the associated significant exchange rate volatility cost. Gali & Monacelli (2005), with a model that features complete exchange rate pass-through for a small open economy, finds that the stabilization of domestic prices is the best welfare-maximizing policy route for a central bank. In addition, Devereux *et al.* (2006), in an open economy setting with complete pass-through and financial constraints, finds that the domestic inflation targeting (DITR) yields the best outcome for welfare; followed by the CPI inflation targeting rule (CITR) and the exchange rate targeting rule (ERTR), respectively. Furthermore, using a welfare loss function derived from the household utility representation in a two country model set-up, Divino (2009) finds that domestic inflation targeting is the optimal policy.

3.5.4 Optimal Policy under discretion and commitment given 10 percent oil price shock

To derive the optimal policy, all information in the endogenous and exogenous variables are utilized to minimize a stated loss function. Optimal policy problems entails finding solution to an optimization problem whose objective function is the loss equation and the constraints are the structural equations in the model. The literature distinguishes between two classes of optimal policy[16]; namely, discretion and commitment. In the discretionary policy, the policy maker solves the one period problem every period. He sets interest rate each period by solving a new optimization problem without dealing with constraints arising from previous period commitment. The policy maker knows he will re-optimize next period, and he is aware that the private sector knows as well. Thus, he takes private sector's expectations about future variables as given. Kydland & Prescott (1977) and Woodford (2003) demonstrates that, when the policy maker cannot commit, the promise of a specific path for the instrument will become time inconsistent. Therefore, reneging on the plan and re-optimizing the next period becomes optimal and the private sector would have absorbed this information. Under discretion, the interest rate reacts only to current period variables, there is no sticking to a policy rule and monetary policy may not be time consistent (Woodford, 2003; Divino, 2009).

Conversely, with optimal policy under commitment to follow a rule, the policy maker minimizes the welfare loss function subject to the rational expectations equilibrium conditions in the model, once and for all, and commits to the resulting optimal policy rule, with no incentive to change course. The solution does not only take current period into account, but also reflects the present discounted value of the flow objective functions. Private agents, believed to be forward looking do consider the commitment by the central bank to a definite policy course in the formation of expectation about the future. Consequently, gains result from commitment given that private agents' expectations is properly anchored. The gain of commitment is in the lowering of future expected changes in current variables in case of exogenous shocks. The policy maker's binding commitment to a future monetary policy reaction function ensures credibility and anchors expectation in the economy.

Table 3.3 presents loss values obtained from discretionary and commitment optimal policy under the alternative central bank's preferences. The commitment[17] policy clearly outperforms discretion under all ten (10) weights combinations. The-

[16]Dynare's toolbox which implements discretionary and commitment policies is used for the numerical solution given simulated oil price shock.

[17]Better long-run outcomes are achieved under commitment. Monetary policy can respond better to shocks if the central bank is duty-bound to honor past promises concerning its future behavior. Commitment allows the policy maker to gain credibility, an asset needed for success in achieving policy objective Clarida *et al.* (1999), Plosser (2007) and Dotsey & Plosser (2008).

Loss values		Preferences (weights)			
Discretion	Commitment	λ_π	λ_y	λ_r	λ_s
0.01030	0.00076	1	0.5	0.5	0.5
0.01330	0.00041	1	1	0.5	0.5
0.01650	0.00028	1	1.5	0.5	0.5
0.01960	0.00022	1	2	0.5	0.5
0.01020	0.00078	1	0.5	1	0.5
0.01000	0.00079	1	0.5	1.5	0.5
0.00970	0.00081	1	0.5	2	0.5
0.00900	0.00130	1	0.5	0.5	1
0.00850	0.00170	1	0.5	0.5	1.5
0.00830	0.00200	1	0.5	0.5	2

Table 3.3: Welfare losses under discretion and commitment policy given 10% oil price shock

oretically, the superior results obtained under commitment over discretion stems from (i) the possible positive inflation bias which results when the central bank tries to steer output above it's potential by exploiting inflation-output trade-off in the short-run (Kydland & Prescott, 1977; Barro & Gordon, 1983); and (ii) the reaction of a discretionary policy maker to shocks is generally, inefficient, leading to higher welfare losses than would obtain in a commitment policy. As evident in the literature, the equilibrium and responses to shocks achievable by a committed policy maker are superior to those achievable by a policy maker who re-optimizes per period. In this exercise, the best outcome under commitment is achieved when the policy maker attaches high weight to output volatility, while the worst outcomes results from the preference that attaches high importance to exchange rate stabilization. The justification for an output-oriented optimal commitment policy can be extracted from the evidence of Dutch disease shown in the impulse response functions and the compelling need for the central bank to act accordingly, to boost domestic output. Whereas, the case of the least optimal policy under commitment imply that caring too much about a highly volatile variable (see table 3.3) like the exchange rate in the loss function is not welfare maximizing and may undermine the spirit of commitment. Under discretionary policy, however, the best policy outcome is associated with the policy maker's preference that accords greater importance to the exchange rate in the welfare loss function. Conversely, the worst policy outcome under the discretionary policy is one which gives greater weight to output in the loss function. The same central bank's preference that produced the best outcome (the least loss value) under commitment yields the worst possible outcome (highest loss value) under discretion; and vice versa.

This finding is somewhat instructive for oil exporting small open economies, where the exchange rate is highly volatile and critical for welfare. Unless these economies are able to achieve domestic economic resilience against external shocks, so they are able to accommodate a considerable degree of exchange rate flexibility, it will be hard for them to pursue a credible commitment optimal policy in reality. Given the Dutch disease situation, the small open economy would need to think of the right balance between output and exchange rate stabilization. In practice[18], full commitment is utopia, as many central banks may be pro-active in their preferences of the loss function weights. However, committing to a medium term inflation and exchange rate paths may pass for a degree of commitment.

3.5.5 Comparing Optimized Simple Rules, Discretion and Commitment policies

Taylor & Williams (2010) argue that when simple rules are optimized the advantage optimal policy has over simple rules becomes insignificant in most models. Their position aligns with findings from an earlier work by Williams (2003), which show that an optimized three parameter interest rate rule which incorporates inertia is comparable in performance to the fully optimal policy counterpart. In addition, Levin *et al.* (2005) submits that the results of optimal policy exercise for one model may be worse than that of the optimized simple rule in another model. From the foregoing, results from the optimized simple rules are believed to closely approximate those from the commitment optimal policy. Therefore, for the purpose of comparison, we present in table 3.4 below the loss values obtained from the optimized simple rules, discretionary and commitment policies given ten (10) policy preferences assuming a 10 percent oil price shock.

Central Bank				Optimized Simple Rules			Optimal Policy	
λ_π	λ_y	λ_r	λ_s	CITR	DITR	ERTR	Discretion	Commitment
1	0.5	0.5	0.5	0.00095	0.00090	0.00094	0.01030	0.00076
1	1	0.5	0.5	0.00120	0.00120	0.00120	0.01330	0.00041
1	1.5	0.5	0.5	0.00130	0.00130	0.00130	0.01650	0.00028
1	2	0.5	0.5	0.00140	0.00140	0.00140	0.01960	0.00022
1	0.5	1	0.5	0.00096	0.00091	0.00095	0.01020	0.00078
1	0.5	1.5	0.5	0.00097	0.00092	0.00095	0.01000	0.00079
1	0.5	2	0.5	0.00098	0.00093	0.00096	0.00970	0.00081
1	0.5	0.5	1	0.00140	0.00120	0.00140	0.00900	0.00130
1	0.5	0.5	1.5	0.00170	0.00150	0.00170	0.00850	0.00170
1	0.5	0.5	2	0.00190	0.00170	0.00190	0.00830	0.00200

Table 3.4: Welfare losses under optimized simple rules, discretion and commitment policy given 10% oil price shock

The overall results of the policy exercises indicates that commitment policy com-

[18]More so for a small open economy

pletely outperforms discretionary policy across all preferences; and largely dominates the optimized simple rules. Under three (3) weight combinations that reflects policy maker's preference to value exchange rate more in the loss function, the DITR produces a better result; while under one (1) weight combination with the highest exchange rate weight of 2 both CITR and ERTR also perform better compared to both commitment and discretion. There is a tie between CITR, ERTR and the commitment policy under one policy preference with high exchange rate weight of 1.5. As shown earlier, a higher weight on exchange rate in the loss function will produce sub-optimal outcomes under commitment and a less sub-optimal outcome under discretion. Our results show that the optimized simple rules of CITR, DITR and ERTR under any policy preferences overwhelmingly outperform the discretionary policy. In terms of general ranking based on welfare loss values, commitment policy leads the pack, followed by the optimized simple rules, especially the one targeting domestic inflation (DITR) and then, the discretion policy.

3.6 Conclusion

In a two-sector small open economy model featuring price stickiness in the non-traded sector and calibrated to highlight some stylized facts about oil exporting emerging and developing small open economies, we study the dynamic responses of selected macroeconomic variables to a positive oil price shock and the alternative optimal paths for monetary policy given the shock. The study indicates evidence of the Dutch disease in the model economy, consequent on the positive oil price shock and finds a monetary policy response that is accommodatory in pursuit of domestic output stabilization.

The incidence of Dutch disease in the economy is found to be more amplified under the CPI targeting rule, as both non-tradable output and total output declined in response to the positive oil price shock. In addition, given that the magnitude of the rise in oil output induced by the oil boom exceeds the size of the decline in domestic output, the net effect resulted to an increase in employment and consumption levels. The income effect from the higher hours of work and the wealth effect resulting from the boom can explain the rise in consumption. Exchange rate appreciation is significant and similar under the three policy regimes; while the threat of inflation is largely subdued, although a positive inflation expectation abounds in the economy. The real exchange rate is revealed as the most volatile variable in the model and this is robust across all monetary policy regimes. The high volatility of the exchange rate may further justify the propriety of incorporating the exchange rate in the monetary policy reaction function of the central bank, in line with Olayeni (2009b) who posits that the exchange rate is not self-correcting.

Evidence from the optimized simple rules policy exercises show that the DITR delivers the superior welfare-maximizing outcome. Next to the DITR, the ERTR rule provides the second best welfare outcome; while the CITR yields the least welfare maximizing results. Although the best optimized simple rule is associated with a policy maker's preference that normalizes inflation's weight to unity and distributes a lesser weight (of 0.5) equally for the remainder variables, the next ranked optimal outcomes under optimized simple rules tend to exhibit sensitivity to higher weight on interest rate in the loss function. Preferences (other than the one referred to earlier which produces the best) with the least weight of 0.5 on interest rate in the loss function are associated with higher welfare losses. Curiously, under three (3) out of the ten (10) preferences, the DITR OSR marginally outperforms the commitment policy; a situation that lends some credence to Levin & Williams (2003), who advocate that the OSR can sometimes produce results that are comparable to the fully optimal policy.

The commitment policy ranks best and wholly outperforms discretion under all preferences. The optimal commitment policy is shown to be sensitive to the policy maker's weight on output stabilization. Divino (2009) echoes a similar result in the context of an open economy. He posits that the openness of the economy has a direct implication for social welfare objective and that the relative weight on output gap stabilization is higher for an open economy than for the closed economy. On the other hand, the performance of the discretion policy is improved with higher weights on the exchange rate. It can be seen from the results that the policy maker's preference that produces the best possible outcome for optimal policy under commitment also leads to the worst possible welfare outcome under the discretion policy. Optimal policy under commitment demands that a higher weight should be attached to domestic output stabilization while the discretion policy's best result is obtained with a higher weight on the exchange rate in our model. This sets up a trade-off between stabilizing the exchange rate (which can be conceived as stabilizing inflation) and stabilizing the output gap. In this model, however, owing to the combined effects of the consequent exchange rate appreciation and the debilitating effect of the Dutch disease on domestic output, the central bank can pursue optimal policy by leaning towards output stabilization. This recommendation is based on the results obtained from the optimal policy exercise under commitment. The domestic inflation targeting regime under optimized simple rules will suit a policymaker with exchange rate stability orientation better than optimal policy under both discretion and commitment policies.

Chapter 4

External Vulnerability and Monetary Policy in Net Oil Exporting Small Open Economies

Appendix 6B: Statement of Authorship

This declaration concerns the article entitled:									
External Vulnerability and Monetary Policy in Net Oil Exporting Small Open Economies									
Publication status (tick one)									
Draft manuscript	x	**Submitted**		**In review**		**Accepted**		**Published**	
Publication details (reference)									
Copyright status (tick the appropriate statement)									
I hold the copyright for this material	x	Copyright is retained by the publisher, but I have been given permission to replicate the material here							
Candidate's contribution to the paper (provide details, and also indicate as a percentage)	The candidate contributed to / considerably contributed to / predominantly executed the… Formulation of ideas: 100% Design of methodology: 100% Experimental work: 100% Presentation of data in journal format: 100%								
Statement from Candidate	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature.								
Signed	Sunday Oladunni	**Date**	25/09/2019						

4.1 Introduction

External sector vulnerability has been at the core of most emerging and developing economies business cycle fluctuations for many decades. The state of the domestic economy determines to a large extent, the size of the impact and amplification of foreign shocks in these economies. Inherent structural weaknesses, inefficiencies and macroeconomic imbalances in the domestic economy tend to exacerbate the impact of adverse external shocks, thereby undermining domestic resilience to such shocks.

The situation in which many oil-dependent small open economies rely predominantly on crude oil export for foreign exchange and government revenue is a pointer to the delicate economic structures in these countries. A large proportion of the expected positive inter-sectoral spillovers, forward and backward linkages from oil production do not materialize. This is because, the oil sectors in most oil producing economies operate as enclave sectors; attracting vast amount of production inputs from abroad and producing almost entirely for export. In addition, unanticipated and prolonged adverse oil price shocks tend to create external vulnerabilities which often snowball into sharp output declines, high inflation, fiscal insolvency, currency crises; thereby leading to welfare losses. Consequently, tough fiscal choices and appropriate monetary policy responses are required to ameliorate the welfare effects of oil-induced vulnerabilities among oil exporting small open economies.

The literature on micro-founded models with oil price shocks, macroeconomic dynamics and monetary policy in net oil exporting small open economies is rather sparse. Medina & Soto (2005), in an estimated New Keynesian small open economy dynamic stochastic general equilibrium (DSGE) model for Chile, incorporated oil in the household consumption bundle and in domestic firms production function and found that a positive oil price shock resulted to higher inflation and lower output. An oil-induced output decline is linked to the endogenous tightening of monetary policy. They also reported that a wage stabilizing monetary policy rule is welfare superior to those targeting core and headline inflation measures, albeit at significant output cost. Poghosyan & Beidas-Strom (2011) estimated a DSGE model for Jordan which feature price and wage rigidities; imported oil as consumption good and production input; and found that oil price shock caused a huge negative income effect, exchange rate rate depreciation and current account improvements. They found also that a pegged exchange rate regime delivers a comparatively low risk premium, with consequential amplifications in consumption, output and inflation volatilities. More recently, Hollander *et al.* (2019) estimated a New Keynesian DSGE model for South Africa, with oil as a consumption good and a production factor; and reports that real oil price shock's effect on output and consumption is significant and persistent. Thus, they concluded that oil price shock is a fundamental driver of inflation, output and interest rates; given that it generated a trade-off between inflation and output stabilization. Their results also suggest that endogenous monetary tightening in response to oil price shock undermined economic recovery in South Africa[1].

This chapter, however, sets up a New Keynesian small open economy DSGE model which embeds some fundamental features of a net oil exporting developing economy. The small open economy produces crude oil exclusively for export. Households and non-oil firms consumption basket and production function, respectively, include imported refined oil. We assume nominal price rigidity in the domestic goods sector (Gali & Monacelli (2005)), a competitive labour market (Hove *et al.* (2015)), the operation of the law of one price gap (Monacelli (2005), Burstein & Gopinath (2014)), a perfectly competitive, non-exogenous[2] enclave oil producing sector, imperfect international risk-sharing, induced endogenously by a debt-sensitive external risk premium and an exogenous oil price shock; oil subsidy (Bouakez *et al.* (2008), Allegret & Benkhodja (2015)) and a monetary policy setting that feature four alternative policy rules popular in most emerging markets and developing economies.

We contribute to the literature in three (3) ways. First, we capture fundamental features of commodity exporters that re-import the commodity they export in another form after foreign value addition; thereby leading to job export, low competitiveness, tax burden of foreign origin, in addition to external vulnerabilities associated with oil earnings volatility[3], imported oil and non-oil inflation and foreign exchange pressures. Second, we established a direct connection between crude and refined oil prices in the model. This is not the case with models by Medina & Soto (2005), Poghosyan & Beidas-Strom (2011) and Hollander *et al.* (2019) which were oriented toward oil importing small open economies that exports non-oil commodity endowments. Consequently, they did not explore the interaction [4] between the two price dynamics. In addition, given that the economies of Chile, Jordan and South Africa modeled, respectively, in the aforementioned papers are fundamentally oil importing, their model features can not approximate the structural realities in SOEs that both export and import oil. Third, we highlight the seeming structural chasm between domestic oil and non-oil sectors in some net oil exporting countries; by assuming that crude oil is exported wholly to the rest of the world and that oil sector attracts capital from the rest of the world in form of foreign direct investments (FDI). Our characterization show the near-zero direct interaction between oil and non-oil sectors among many developing oil exporters and captures the low levels of

[1] All three models see the world from the angle of an oil importer.

[2] Crude oil output is modeled explicitly, as opposed to the popular trend of simply assuming it to be an exogenous process.

[3] Due to commodity price fluctuations.

[4] The interaction between exported crude and imported petroleum prices is key to underlining external vulnerability in our model

industrialization in these economies.

Models developed for advanced oil exporting countries such as Dib (2008) for Canada; and Ferrero & Seneca (2015) and Bergholt *et al.* (2017) for Norway cannot be situated in the context of net oil exporting developing and emerging market economies. These models are enriched with strong domestic inter-sectoral industrial interactions which often generate significant positive spillovers between the oil sector and the mainland economy. They generally tend to embed fiscal rules designed to promote national savings and de-link the domestic economy from the direct effects of oil price volatility. This is achieved through the operation of a sovereign wealth fund, where oil profits are warehoused and managed. These features have not yet taken roots in many oil exporting developing countries. The closest strand of literature to our model include Allegret & Benkhodja (2015) for Algeria, Algozhina (2016) for Kazakhstan and Iklaga (2017) for Nigeria; but they do not account for our observations and resultant contributions. For instance in the case of Nigeria, Iklaga (2017) assumed domestic oil sector variables to be wholly exogenous, such that both oil output and price evolve exogenously. Whereas in our model, crude oil production is endogenously modeled, allowing the oil firm to utilize domestic labour and imported capital in its production function. Only oil price is deemed to be exogenous. Furthermore, to our knowledge, no attempt had been made in the New Keynesian DSGE literature for net oil exporting developing and emerging market economies to highlight the relationship between crude and refined oil prices.

Given our model characterization, we simulate a negative oil price shock and analyze the consequent macroeconomic responses under alternative monetary policy specifications and oil subsidy regimes. Using optimized simple rules, we test for the welfare implications of implementing the alternative policy rules under three oil subsidy scenarios given the oil price shock. Optimized simple rules allow for the possibility of generating robust rules among competing alternative models for setting interest rate (Taylor & Williams, 2010). In the aftermath of the shock, the economy experiences stagflation. Stagflation manifests via the income and exchange rate channels, while increased household external borrowing to smooth consumption and cushion the effects of fallen income, higher lump-sum tax, rising unemployment, volatile wages and higher inflation led to an increase in the external risk premium. In a full subsidy environment, the kind of target variable in the Taylor rule appears not to matter, as macroeconomic responses to the shock under all monetary policy specifications exhibit extreme similarity, a development which suggests that oil subsidy may have undermined monetary policy transmission mechanism in the model. Given free labour mobility, the adverse shock to the oil sector encouraged movement of workers from the sector to the non-oil sector, thereby boosting non-oil sector productivity and output. The central bank responds to inflation and exchange rate pressures by raising the interest rate.

Macroeconomic fluctuations under partial and zero subsidy regimes follow similar directional patterns as under the full subsidy regime, but response speed and magnitudes are more pronounced under the former. Although, the monetary policy rule with oil inflation target is associated with less sharp impact response of oil consumption, aggregate consumption and aggregate output, it is characterized by slightly higher volatility over time, compared to other monetary policy rules. Monetary policy response was least aggressive on impact under oil inflation targeting rule but later became aggressive as the initial fall in oil inflation reversed. Tight external borrowing condition added an extra source of external vulnerability to the negative oil shock. The optimized simple rules policy exercises show that either core or oil inflation targeting maximizes welfare in a full subsidy scenario, while targeting oil inflation is shown to be welfare superior assuming a partial or zero subsidy scenarios. This outcome presents a challenge in a rule-based interest rate setting environment, as the policy maker may jeopardize its credibility as it responds to movement in oil price, an exogenous and highly volatile variable. Our results suggest that oil subsidy can play a role in moderating adverse oil shock-induced business cycle fluctuations and can be welfare maximizing, although, our model assumes efficiency in oil subsidy administration.

The rest of the chapter is organized as follows. Following the introduction is section 2, which describes model environment and equations underpinning behaviour of agents and the resulting equilibrium conditions. Section 3 presents model calibration, solution and simulation, while in section 4, we analyze simulation results. In section 5, we evaluate welfare under the optimized simple rules and section 6 concludes the paper.

4.2 Model

4.2.1 Model Environment

We model an oil-endowed small open economy[5] with structural characteristics of emerging or developing economies. There is a representative household whose consumption bundle includes imported refined oil, core domestic and foreign goods. The household can access international capital market for consumption smoothing purposes. However, an endogenous external debt-sensitive risk premium term introduces a financial friction which does not allow for perfect international risk sharing.

On the firms side, two categories of representative firms exist; the first is a monopolistically competitive firm that combines labour and refined oil to produce core goods for domestic consumption and export; and the second operates as a perfectly competitive firm, utilizing a production function that includes labour and foreign oil capital to produce crude oil exclusively for export. There is an importer with a pricing mechanism based on Calvo (1983b) just like the monopolistically competitive domestic firm. However, import price is subject to the law of one price gap in the spirit of Monacelli (2005), reflecting exchange rate incomplete pass-through.

The labour market is assumed to be competitive, allowing perfect cross-sectors mobility of workers. The domestic assets market functions to ensure a zero net supply of domestic bonds. The government levy lump-sum tax on households and oil tax on oil producing firm's net revenue. The post-tax balance of oil firm's net revenue constitute returns on foreign capital and it is paid to foreign direct investors. In addition, the government consumes domestic and foreign goods. It also provides sovereign guarantees for households external debt obligations.

[5] As shown in figure 4.1

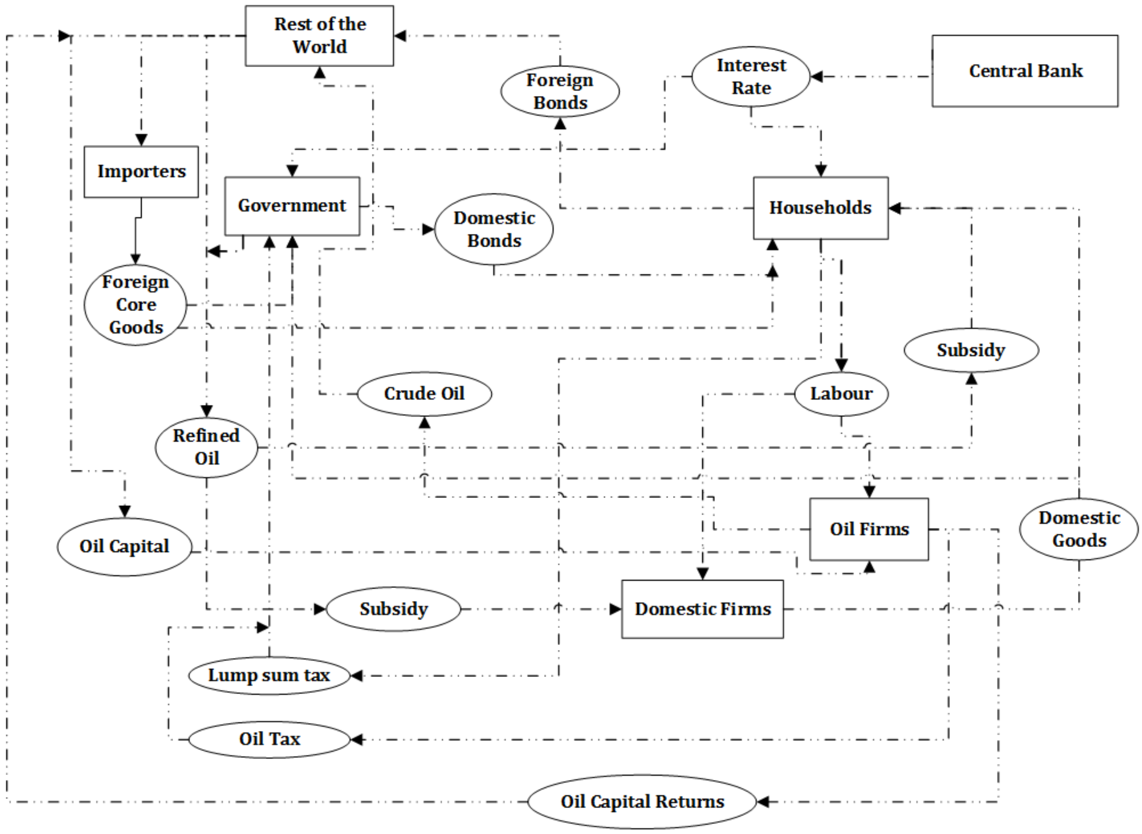

Figure 4.1: Overview of Model

The central bank cares about agents welfare and sets the interest rate according to the Taylor rule specification(s) that shows the objective to minimize output and inflation or exchange rate volatility. The policy maker must choose the particular inflation measure to target as an instrument variable in the Taylor rule. For the model economy, the variants we consider include headline inflation, core inflation and oil inflation. Either of the three is to be combined with either output or the real exchange rate to anchor inflation expectations, promote macroeconomic stability and maximize welfare in the economy. Our optimal monetary policy exercise compares outcomes of optimized simple rules given a negative oil price shock under alternative monetary policy specifications and oil subsidy regimes. The rest of the world is assumed to evolve exogenously.

4.2.2 Households

The economy is inhabited by a continuum of infinitely lived households indexed by $i \in [0, 1]$. Following the One-Agent New Keynesian (OANK) modeling approach referenced in Gali (2018), we model a typical Ricardian representative household, who has access to both domestic and foreign capital markets. However, risk sharing is imperfect owing to an external risk premium.

4.2.2.1 Household Intra-temporal Consumption

Household total consumption bundle (C_t) is a composite of core (non-oil) goods and refined oil; represented as follows:

$$C_t = \left[(1-\Psi_{ro})^{\frac{1}{\nu}}(C_t^c)^{\frac{\nu-1}{\nu}} + \Psi_{ro}^{\frac{1}{\nu}}(C_t^{ro})^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}} \tag{4.1}$$

Where C_t^c is core consumption, C_t^{ro} is (refined) oil consumption, Ψ_{ro} and $1-\Psi_{ro}$ are shares of refined oil and core goods, respectively in the composite consumption basket; while ν represents the elasticity of substitution between core and oil consumption. Core consumption, following a constant elasticity of substitution (CES) aggregator, is composed of domestically produced and imported goods. It is given as follows:

$$C_t^c = \left[(1-\Psi_f)^{\frac{1}{\varpi}}(C_t^h)^{\frac{\varpi-1}{\varpi}} + \Psi_f^{\frac{1}{\varpi}}(C_t^f)^{\frac{\varpi-1}{\varpi}}\right]^{\frac{\varpi}{\varpi-1}} \tag{4.2}$$

Where C_t^h and C_t^f are the bundles of domestically produced and imported core goods, respectively. The parameter $1-\Psi_f$ is the home bias term in household consumption, Ψ_f is the share of imported core goods in domestic consumption and ϖ represents the intra-temporal elasticity of substitution associated with each group of domestically produced goods and imported foreign produced goods in the core consumption bundle. The resulting aggregate consumer price index (CPI) is:

$$P_t = \left[(1-\Psi_{ro})(P_t^c)^{1-\nu} + \Psi_{ro}(P_t^{ro})^{1-\nu}\right]^{\frac{1}{1-\nu}} \tag{4.3}$$

Where P_t^c and P_t^{ro} are the price of core goods and imported refined oil, respectively. The price index associated with core consumption bundles is as follows:

$$P_t^c = \left[(1-\Psi_f)(P_t^h)^{1-\varpi} + \Psi_f(P_t^f)^{1-\varpi}\right]^{\frac{1}{1-\varpi}} \tag{4.4}$$

Where P_t^h and P_t^f represents the price of domestically produced and imported goods, respectively in the core goods consumption basket. The total household expenditure $[P_t^c C_t^c + P_t^{ro} C_t^{ro} = P_t C_t]$ can be minimized subject to the CES consumption aggregator in 4.1 to determine household optimal allocation for the aggregate consumption. Thus, the demand for core goods and refined oil in the aggregate consumption are as follows:

$$C_t^c = 1-\Psi_f \left(\frac{P_t^c}{P_t}\right)^{-\nu} C_t \tag{4.5}$$

$$C_t^{ro} = \Psi_{ro} \left(\frac{P_t^{ro}}{P_t}\right)^{-\nu} C_t \tag{4.6}$$

The demand functions for domestically produced and imported goods, resulting from household minimization of core expenditure $\left[P_t^h C_t^h + P_t^f C_t^f = P_t^c C_t^c\right]$ subject to the CES core consumption aggregator in 4.2 are given as follows:

$$C_t^h = 1 - \Psi_f \left(\frac{P_t^h}{P_t^c}\right)^{-\varpi} C_t^c \tag{4.7}$$

$$C_t^f = \Psi_f \left(\frac{P_t^f}{P_t^c}\right)^{-\varpi} C_t^c \tag{4.8}$$

When log transformation is performed on equations 4.3 and 4.4, the following price indices result:

$$P_t = (P_t^c)^{1-\Psi_{ro}} (P_t^{ro})^{\Psi_{ro}} \tag{4.9}$$

$$P_t^c = (P_t^h)^{1-\Psi_f} (P_t^f)^{\Psi_f} \tag{4.10}$$

Going forward, the Uhlig (1995)'s linearization method is used to perform log-linearization on the characterizing equations of the model. It involves taking the log deviation of each expression around their steady-state values. Each lower case variable capped with tilde should be taken as the log-deviation of the corresponding upper case variable from its steady state value.

The corresponding log-linearized price indices in 4.9 and 4.10 are:

$$\tilde{p}_t = (1 - \Psi_{ro})\tilde{p}_t^c + \Psi_{ro}\tilde{p}_t^{ro}$$

$$\tilde{p}_t^c = (1 - \Psi_f)\tilde{p}_t^h + \Psi_f \tilde{p}_t^f$$

Substituting P_t in 4.5 and 4.6; and P_t^c in 4.7 and 4.8, respectively; we obtain the following new corresponding sets of demand functions:

$$C_t^c = (1 - \Psi_{ro}) \left(\frac{P_t^{ro}}{P_t^c}\right)^{\nu\Psi_{ro}} C_t \tag{4.11}$$

$$C_t^{ro} = \Psi_{ro} \left(\frac{P_t^{ro}}{P_t^c}\right)^{-\nu(1-\Psi_{ro})} C_t \tag{4.12}$$

$$C_t^h = 1 - \Psi_f \left(\frac{P_t^f}{P_t^h}\right)^{\varpi\Psi_f} C_t^c \tag{4.13}$$

$$C_t^f = \Psi_f \left(\frac{P_t^f}{P_t^h} \right)^{-\varpi(1-\Psi_f)} C_t^c \tag{4.14}$$

We can further substitute 4.11 into 4.13 and 4.14 to derive the following functions:

$$C_t^h = (1-\Psi_f)\left(\Upsilon_t\right)^{\varpi\Psi_f}(1-\Psi_{ro})\left(\frac{P_t^c}{P_t^{ro}} \right)^{-\nu\Psi_{ro}} C_t \tag{4.15}$$

$$C_t^f = \Psi_f\left(\Upsilon_t\right)^{-\varpi(1-\Psi_f)}(1-\Psi_{ro})\left(\frac{P_t^c}{P_t^{ro}} \right)^{-\nu\Psi_{ro}} C_t \tag{4.16}$$

Where Υ_t is the terms of trade $\left(\frac{P_t^f}{P_t^h}\right)$, as defined by Gali & Monacelli (2005). Log linearizing[6] 4.12, 4.15 and 4.16, we obtain the following expressions:

$$\tilde{c_t}^h = (\varpi\Psi_f)\tilde{\Upsilon}_t + (-\nu\Psi_{ro})(\tilde{p}_t^c - \tilde{p}_t^{ro}) + \tilde{c}_t \tag{4.17}$$

$$\tilde{c_t}^f = -\varpi(1-\Psi_f)\tilde{\Upsilon}_t + (-\nu\Psi_{ro})(\tilde{p}_t^c - \tilde{p}_t^{ro}) + \tilde{c}_t \tag{4.18}$$

$$\tilde{c_t}^{ro} = -\nu(1-\Psi_{ro})(\tilde{p}_t^{ro} - \tilde{p}_t^c) + \tilde{c}_t \tag{4.19}$$

4.2.2.2 Household Inter-temporal preferences

The representative household maximizes an expected inter-temporal utility of the form:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{C_t^{1-\eta}}{1-\eta} - \frac{L_t^{1+\varrho}}{1+\varrho} \right\} \tag{4.20}$$

Where the expectation operator is E_0, the discount factor is β^t, a composite consumption goods index is represented as C_t and household hours of work are given as L_t. The relative risk aversion coefficient, otherwise known as inverse of the elasticity of inter-temporal substitution is represented as η and it is a measure of the utility function curvature. The elasticity of the marginal dis-utility of labour is ϱ. The household's budget constraint is defined as follows:

$$P_t^{ro}C_t^{ro} + P_t^h C_t^h + P_t^f C_t^f + B_t + \left(\digamma_t\left(\frac{S_t B_t^*}{P_t Y_t}, \epsilon_t^{\digamma} \right) R_t^* \right)^{-1} S_t B_{t+1}^* + \tau_t \leq S_t B_t^* + (R_t)^{-1} B_{t+1} + W_t L_t + \Pi_t^h \tag{4.21}$$

[6] Log-linearized variables are expressed in lowercase with tilde and steady state variables are those with with bars and no time subscripts.

Summarizing all the consumption types in the composite consumption bundle of the household, the expression can be written as:

$$P_tC_t + B_t + \left(\Gamma_t\left(\frac{S_tB_t^*}{P_tY_t}, \epsilon_t^{\Gamma}\right) R_t^*\right)^{-1} S_tB_{t+1}^* + \tau_t \leq \\ (R_t)^{-1} B_{t+1} + S_tB_t^* + W_tL_t + \Pi_t^h \tag{4.22}$$

Where $P_tC_t = P_t^{ro}C_t^{ro} + P_t^hC_t^h + P_t^fC_t^f$, being the household total consumption expenditure, which include expenditure on imported refined oil $P_t^{ro}C_t^{ro}$, domestically produced goods $P_t^hC_t^h$ and imported core goods $P_t^fC_t^f$. The household has access to one period unit of domestic bond, B_t and one period unit of foreign bond B_t^* at the nominal gross returns[7] of R_t and R_t^*, respectively. A unit of domestic bond B_t is purchased while a unit of foreign currency denominated bond $S_tB_t^*$ is issued at time (t); and they attract the gross nominal returns of $(R_t)^{-1} B_t$ and $\left(\Gamma_t\left(\frac{S_tB_t^*}{P_tY_t}, \epsilon_t^{\Gamma}\right) R_t^*\right)^{-1} S_tB_t^*$, respectively at time $(t+1)$. $\Gamma_t\left(\frac{S_tB_t^*}{P_tY_t}, \epsilon_t^{\Gamma}\right)$ is the small open economy's endogenous risk premium associated with private foreign bonds and it is influenced by the ratio of the country's net foreign asset/debt to gross domestic product (GDP) and a stochastic risk premium shock (ϵ_t^{Γ}) in the spirit of Garcia & Gonzalez (2013). A net debtor small open economy issuing foreign debt must pay an extra cost (a risk premium) in addition to a foreign risk-free interest rate. Conversely, if the small open economy is a net creditor, it receives returns less than the foreign risk-free interest rate as foreign bond holders factor in the country risk premium.

In addition, the inclusion of the risk premium reflects the empirical evidence in support of the existence of an international financial friction or imperfect international capital mobility as in Benigno (2001) in which domestic agents must pay a premium above the foreign risk-free interest rate in order to access foreign funding. In addition, risk premium on foreign bonds has been shown by Schmitt-Grohe & Uribe (2003) to be an important requirement for inducing stationarity in the small open economy's total net foreign assets/debts. In a world characterized by perfect international financial market, there will be complete international risk sharing and the the risk premium Γ_t will be equal to unity. S_t is the nominal exchange rate, W_tL_t is wages received from hours of work, Π_t^h is the profits received from ownership of firms producing domestic goods and τ_t is the lump-sum tax.

The optimizing household chooses the combination of consumption C_t, labour supply L_t, domestic savings B_t and foreign borrowings B_t^*, respectively, which maximizes its inter-temporal utility in 4.20 subject to the consequent budget constraint

[7] $R_t = 1+i$ and $R_t^* = 1+i^*$ being the gross returns on domestic and foreign bonds, respectively.

in 4.22. The first order conditions (FOCs) defines the household's labour-leisure choice, consumption-domestic saving (borrowing) decision and consumption-foreign savings (borrowing) decision as follows:

$$C_t^{\eta} L_t^{\varrho} = \frac{W_t}{P_t} \tag{4.23}$$

$$1 \quad = \quad \beta E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\eta} \left(\frac{P_t}{P_{t+1}} \right) R_t \right] \tag{4.24}$$

$$1 = \beta E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\eta} \left(\frac{P_t}{P_{t+1}} \right) \left(\frac{S_{t+1}}{S_t} \right) \digamma_t \left(\frac{S_t B_t^*}{P_t Y_t}, \epsilon_t^{\digamma} \right) R_t^* \right] \tag{4.25}$$

Equation 4.23 is the labour supply equation; which indicates that the optimal labor-leisure decision must be such that the marginal rate of substitution between consumption and hours of work or leisure equates the real wage. The inter-temporal optimality conditions with respect to domestic and foreign bonds, otherwise known as the Euler equations are represented by equations 4.24 and 4.25, respectively. The log-linear versions of equations 4.23 and 4.24 are as follows[8]:

$$\eta \tilde{c}_t + \varrho \tilde{l}_t = \tilde{w}_t - \tilde{p}_t \tag{4.26}$$

$$\tilde{c}_t = E_t \tilde{c}_{t+1} - \frac{1}{\eta} \left(\tilde{i}_t - E_t \tilde{\pi}_{t+1} \right) \tag{4.27}$$

4.2.3 Domestic Goods Firms

The representative firm produces non-oil final goods for domestic and foreign consumption.

4.2.3.1 Production

The firm combines labour hours L_t^h and imported refined oil RO_t^h to produce differentiated goods for both domestic and foreign consumption. It seeks to achieve profit maximization by selecting the price of its variety subject to demand functions and available technology. The total output of a given variety j^h is $Y_t^h \left(j^h \right)$ and the applicable CES production technology can be expressed as:

$$Y_t^h \left(j^h \right) = Z_t^h \left[\vartheta_h^{\frac{1}{\omega_h}} \left(RO_t^h (j^h) \right)^{1 - \frac{1}{\omega_h}} + (1 - \vartheta_h)^{\frac{1}{\omega_h}} \left(L_t^h (j^h) \right)^{1 - \frac{1}{\omega_h}} \right]^{\frac{\omega_h}{\omega_h - 1}} \tag{4.28}$$

[8]Equations 4.24 and 4.25 are treated further under incomplete risk-sharing

Where Z_t^h represent productivity variable in the domestically produced goods sector, assumed to evolve as an auto-regressive process, and common to all firms. The imported refined oil RO_t^h and labour employed L_t^h are used to produce the variety j^h. The weights of refined oil and labour in production are given by ϑ_h and $1-\vartheta_h$, respectively; while the degree of factor substitution between refined oil and labour is defined by ω^h. This parameter is crucial in the determination of the significance of the impact of shocks to refined oil on domestic firms' marginal cost, output and core inflation. The production function for the domestic goods producing firm, in log-linear terms, is given as:

$$\tilde{y}_t^h = \tilde{z}_t^h + \vartheta_h \tilde{ro}_t^h + (1-\vartheta_h)\tilde{l}_t^h \tag{4.29}$$

4.2.3.2 Inputs, Marginal cost and Demand Functions

The optimal inputs mix of firms can be determined by minimizing the firm's total inputs cost subject to technology constraint. This can be expressed as follows:

$$Minimize \qquad W_t L_t^h(j^h) + P_t^{ro} RO_t^h(j^h)$$

$$s.t: \qquad Y_t^h\left(j^h\right) = Z_t^h\left[\vartheta_h^{\frac{1}{\omega_h}}\left(RO_t^h(j^h)\right)^{1-\frac{1}{\omega_h}} + (1-\vartheta)^{\frac{1}{\omega_h}}\left(L_t^h(j^h)\right)^{1-\frac{1}{\omega_h}}\right]^{\frac{\omega_h}{\omega_h-1}} \tag{4.30}$$

The first order conditions from maximizing 4.30 with respect to labour $L_t^h(j^h)$ and refined oil $RO_t^h(j^h)$, respectively yields the following:

$$0 = W_t - NMC_t^h(1-\vartheta_h)^{\frac{1}{\vartheta_h}}\left(\frac{Y_t^h}{L_t^h(j^h)}\right)^{\frac{1}{\omega_h}}$$

$$0 = P_t^{ro} - NMC_t^h(\vartheta_h)^{\frac{1}{\vartheta_h}}\left(\frac{Y_t^h}{RO_t^h(j^h)}\right)^{\frac{1}{\omega_h}}$$

From these two first order conditions above, we obtain the following expressions 4.31 - 4.33:

$$\frac{1-\vartheta_h}{\vartheta_h}\left(\frac{RO_t^h(j^h)}{L_t^h(j^h)}\right) = \left(\frac{W_t}{P_t^{ro}}\right)^{\omega_h} \tag{4.31}$$

In log-linear form 4.31 becomes:

$$\tilde{ro}_t^h - \tilde{l}_t^h = \omega_h(\tilde{w}_t - \tilde{p}_t^{ro})$$

$$L_t^h = (1-\vartheta_h)\left(\frac{NMC_t^h}{W_t}\right)^{\omega_h} Y_t^h \tag{4.32}$$

$$RO_t^h = \vartheta_h \left(\frac{NMC_t^h}{P_t^{ro}}\right)^{\omega_h} Y_t^h \tag{4.33}$$

Substituting L_t^h and RO_t^h into Y_t^h, and re-arranging the resultant expression leads to the nominal marginal cost expression as follows:

$$NMC_t^h = (Z_t^h)^{-\frac{1}{\omega_h}} \left[\vartheta_h (P_t^{ro})^{1-\omega_h} + (1-\vartheta_h) W_t^{1-\omega_h}\right]^{\frac{1}{1-\omega_h}} \tag{4.34}$$

In log-linear forms, the nominal and real marginal cost are as follows:

$$n\tilde{m}c_t^h = -\frac{1}{\omega_h}\tilde{z}_t^h + \vartheta_h(\tilde{p}_t^{ro} - \tilde{p}_t^h) + (1-\vartheta_h)\tilde{w}_t \tag{4.35}$$

$$r\tilde{m}c_t^h = -\frac{1}{\omega_h}\tilde{z}_t^h + \vartheta_h(\tilde{p}_t^{ro} - \tilde{p}_t^h) + (1-\vartheta_h)\tilde{w}_t - (\tilde{p}_t^h - \tilde{p}_t) \tag{4.36}$$

Where the domestic price of imported refined oil assuming government subsidy is given as:

$$P_t^{ro} = S_t P_t^{ro*} - \Theta_t \tag{4.37}$$

Domestic goods sector productivity $\tilde{z}_t^h$ evolves exogenously as follows:

$$\tilde{z}_t^h = \rho_{z^h}\tilde{z}_{t-1}^h + \varepsilon_t^{z^h} \qquad\qquad \varepsilon_t^{z^h} \sim N(0, \sigma_{z^h}^2)$$

The quantity of domestically produced goods sold at home and abroad are represented by $C_t^h\left(j^h\right)$ and $C_t^{h*}\left(j^h\right)$, respectively; while the corresponding demand functions for a particular good variety can be expressed as follows:

$$C_t^h\left(j^h\right) = \left(\frac{P_t^h(j^h)}{P_t^h}\right)^{-\epsilon_h} Y_t^h \qquad \textit{and} \qquad C_t^{h*}\left(j^h\right) = \left(\frac{P_t^{h*}(j^h)}{P_t^{h*}}\right)^{-\epsilon_h} Y_t^{h*}$$

Where $P_t^h(j^h)$ is the price of domestically produced good variety j^h sold at home and $P_t^{h*}(j^h)$ is the foreign currency price of domestic good variety sold abroad. The parameter ϵ_h represents the demand elasticity for domestic good variety j^h while P_t^h and P_t^{h*} are the aggregate price indices for the goods variety sold domestically and abroad, respectively.

4.2.3.3 Domestic Goods Price Setting

Domestic firms are assumed to face monopolistic competition in the home market such that domestic pricing is staggered a la Calvo (1983b); whereas pricing of the export component of the domestically produced variety is perfectly competitive[9]. Domestically, a fraction of the firms with the probability of $1-\theta^h$ receives a price adjustment signal at time t and thus re-optimizes at $t+1$ while another fraction with the probability θ^h are stuck with the previous period price because they do not receive the signal for price reset[10]. Thus $\theta^h \in (0,1)$ represents a measure of price stickiness or nominal rigidity associated with the pricing for home produced goods. The fraction $\frac{1}{1-\theta^h}$ represents the period of time domestic goods prices are expected to remain inflexible.

In addition, we assume that firms that can re-optimize[11] every period are in two categories, namely: "forward-looking and backward-looking firms". The forward-looking firms adjust prices optimally using all the information at their disposal at the time of decision making. Backward-looking firms on the other hand, depend on a rule of thumb for setting prices. They assume information available to them is sticky, consequently they extract and process such information with delay and utilize their knowledge about the historical evolution of price levels to set prices. To reset their prices $P_t^h(j^h)$, backward-looking firms index current prices to previous period inflation. The index of domestic prices is given as:

$$P_t^h(j^h) = P_{t-1}^h(j^h)\left(\frac{P_{t-1}^h}{P_{t-2}^h}\right)^{\theta^h} \tag{4.38}$$

The aggregate domestic price index can be expressed as:

$$P_t^h = \left\{(1-\theta^h)(\overset{reset}{P_t^h})^{1-\epsilon_h} + \theta^h\left[P_{t-1}^h\left(\frac{P_{t-1}^h}{P_{t-2}^h}\right)^{\theta^h}\right]^{1-\epsilon_h}\right\}^{\frac{1}{1-\epsilon_h}} \tag{4.39}$$

Where $\overset{reset}{P_t^h}(j^h)$ is the new price set by an optimizing domestic firm producing good j^h variety to maximize the present discounted value of expected future profits (or dividend) stream. The following expression can be obtained by log-linearizing equation 4.39 and taking first difference:

$$\tilde{\pi}_t^h = (1-\theta^h)(\overset{reset}{\tilde{p}_t^h} - \tilde{p}_{t-1}^h) + (\theta^h)^2\tilde{\pi}_{t-1}^h \tag{4.40}$$

Firms maximize profit after a new price is set at time t subject to the relevant

[9]All goods for exports are competitively priced

[10]Price stickiness exists in the short-run due to staggered prices, menu cost, coordination failure, etc (Snowdon & Vane, 2005 and Junior, 2016)

[11]Reset their prices

demand functions. This problem can be set up as follows:

$$\underset{\overset{reset}{P_t^h}}{Max} \sum_{t=0}^{\infty} (\theta^h)^k E_t \left\{ Q_{t+k} Y_{t+k}^h(j^h) \left[\overset{reset}{P_t^h} - RMC_{t+k}^h P_{t+k}^h \right] \right\}$$

$$s.t.$$

$$Y_{t+k}^h(j^h) = \left(\frac{\overset{reset}{P_t^h}(j^h)}{P_{t+k}^h} \right)^{-\epsilon_h} \left(C_{t+k}^h + G_{t+k}^h + C_{t+k}^{h*} \right) \quad (4.41)$$

Equation 4.41 captures the optimizing firm's discounted expected stream of profits constrained by the total demand for good j^h variety from domestic households C_{t+k}^h, government G_{t+k}^h and foreign households C_{t+k}^{h*}. Real marginal cost is RMC_{t+k}^h while the stochastic discount factor is $Q_{t+k} = \frac{1}{R_{t+1}}$. Taking the first order condition of the scheme in 4.41 yields the following expression:

$$\sum_{t=0}^{\infty} (\theta^h)^k E_t \left\{ Q_{t+k} Y_{t+k}^h(j^h) \left[\overset{reset}{P_t^h} - \frac{\epsilon_h}{\epsilon_h - 1} NMC_{t+k}^h \right] \right\} = 0 \quad (4.42)$$

Where the expression $\frac{\epsilon_h}{\epsilon_h - 1}$ is the mark up and has been regarded as the flexible price marginal cost as in Galí (2008) and $RMC_{t+k}^h = \frac{NMC_{t+k}^h}{P_{t+k}^h}$ is real marginal cost. From 4.24 $Q_{t+k} = \frac{1}{R_{t+1}}$ and $E_t(Q_{t+1}) = \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\eta} \left(\frac{P_t}{P_{t+1}} \right)$; implying that $Q_{t+k} = \beta^k E_t \left(\frac{C_{t+k}^h}{C_t^h} \right)^{-\eta} \left(\frac{P_t}{P_{t+k}} \right)$. Substituting Q_{t+k} in 4.42 and log-linearizing the resulting equation around a zero-inflation steady state leads to the following expression:

$$\overset{reset}{\tilde{p}_t^h} = \tilde{p}_{t-1}^h + \tilde{\pi}_t^h + \sum_{t=1}^{\infty} (\beta\theta^h)^k \left\{ E_t\left(\tilde{\pi}_{t+k}^h\right) + \left(1 - \beta\theta^h\right) E_t\left(r\tilde{m}c_{t+k}^h\right) \right\} \quad (4.43)$$

The New Keynesian Philips Curve is obtained by solving equation 4.43 recursively and re-arranging the resulting equation as follows:

$$\overset{reset}{\tilde{p}_t^h} - \tilde{p}_{t-1}^h = \beta\theta^h E_t\left(\tilde{\pi}_{t+1}^h\right) + \tilde{\pi}_t^h + \left(1 - \beta\theta^h\right) r\tilde{m}c_t^h \quad (4.44)$$

Finally, we substitute equation 4.40 into 4.44 to obtain the domestic goods Hybrid Philips curve as follows:

$$\tilde{\pi}_t^h = \left(1 - \beta\theta^h\right) E_t\left(\tilde{\pi}_{t+1}^h\right) + \theta^h \tilde{\pi}_{t-1}^h + \kappa_t^h r\tilde{m}c_t^h \quad (4.45)$$

Where $\kappa_t^h = \frac{\left(1-\beta\theta^h\right)\left(1-\theta^h\right)}{\theta^h}$ is the coefficient of marginal cost as derived from the substitution process above. The Hybrid New Keynesian Philips Curve equation in

4.45 indicates that domestic inflation dynamics in the small open economy is largely determined by the forward-looking $E_t\left(\tilde{\pi}^h_{t+1}\right)$, the backward-looking $\tilde{\pi}^h_{t-1}$ inflation elements and firm's real marginal cost.

4.2.4 Imports Price Setting and Incomplete pass-through

A representative retailer imports final core good from the rest of the world and applies a mark up on the foreign price of imported good. This gives rise to a wedge between the foreign price of import P^{f*}_t and the domestic price of import P^f_t. Thus, preventing the the law of one price from holding and resulting to law of one price gap ψ_t (Monacelli, 2005). In addition, Burstein & Gopinath (2014) document, based on empirical evidence, that the pass-through from import prices to domestic prices is somewhat subdued; thus generating a deviation from the law of one price. The law of one price gap has been defined as follows:

$$\psi_t = \frac{S_t P^{f*}_t}{P^f_t} \tag{4.46}$$

Analogous to the pricing for domestic goods, the import retailer faces a downward sloping demand curve for imported goods of the form:

$$C^f_{j,t} = \Psi_f \left(\frac{P^f_{j,t}}{P^c_t}\right)^{-\epsilon_f} C^c_t$$

Import good pricing is subject to Calvo (1983b)'s staggered pricing mechanism. A ratio $1-\theta^f$ can re-optimize while the ratio θ^f cannot change their price. Among importers that can re-optimize, a group is "backward-looking" and the other "forward-looking". Following the procedure leading to the derivation of equation 4.43 for domestic goods, the optimal import pricing behaviour can be defined as follows:

$$\overset{reset}{\tilde{p}^f_t} - \tilde{p}^f_{t-1} = \tilde{\pi}^f_t + \sum_{t=1}^{\infty} (\beta\theta^f)^k \left\{E_t\left(\tilde{\pi}^f_{t+k}\right) + \left(1-\beta\theta^f\right) E_t\left(r\tilde{m}c_{t+k}\right)\right\} \tag{4.47}$$

The recursive solution to equation 4.47, when re-arranged produces the typical Hybrid New Keynesian Phillip's curve which expresses the average imported inflation as a function of the expected import inflation, lagged import inflation and the law of one price gap; as follows:

$$\tilde{\pi}^f_t = \left(1-\beta\theta^f\right) E_t\left(\tilde{\pi}^f_{t+1}\right) + \theta^f \tilde{\pi}^f_{t-1} + \kappa^f_t \tilde{\psi}_t \tag{4.48}$$

Where $\tilde{\psi}_t$ being the law of one price gap, is equivalent to the real marginal cost RMC_t of imports. In log-linear form, $\tilde{\psi}_t = \tilde{s}_t + p^{f*}_t - p^f_t \equiv q_t - rp^f_t$. θ^f is the import price stickiness parameter and $\kappa_t^f = \frac{(1-\beta\theta^f)(1-\theta^f)}{\theta^f}$ is the coefficient of the law of one price gap. If $\tilde{\psi}_t \equiv 1$, then law of one price holds, implying that the foreign price of imports $\tilde{p}_t^{f*}$ equates domestic currency price of imports, $\tilde{p}_t^f$.

4.2.5 Inflation Aggregation

Equations 4.3 and 4.4, when differenced and log-linearized produces the following core and aggregate inflation equations:

$$\tilde{\pi}_t^c = (1 - \Psi_f)\,\tilde{\pi}_t^h + \Psi_f \tilde{\pi}_t^f \tag{4.49}$$

$$\tilde{\pi}_t = (1 - \Psi_{ro})\,\tilde{\pi}_t^c + \Psi_{ro}\tilde{\pi}_t^{ro} \tag{4.50}$$

Substituting 4.50 in 4.49, we obtain:

$$\tilde{\pi}_t = (1 - \Psi_{ro})(1 - \Psi_f)\,\tilde{\pi}_t^h + (1 - \Psi_{ro})\,\Psi_f \tilde{\pi}_t^f + \Psi_{ro}\tilde{\pi}_t^{ro} \tag{4.51}$$

From 4.49, 4.50 and 4.51, we obtain the core inflation in 4.52, an expression that incorporates aggregate inflation and the difference of the refined oil price. Equation 4.51 can be re-written as 4.53 following:

$$\tilde{\pi}_t^c = \tilde{\pi}_t - \frac{\Psi_{ro}}{1 - \Psi_{ro}}\left(\tilde{rp}_t^{ro} - \tilde{rp}_{t-1}^{ro}\right) \tag{4.52}$$

$$0 = \Psi_{ro}\tilde{rp}_t^{ro} + (1 - \Psi_{ro})(1 - \Psi_f)\,\tilde{rp}_t^h + (1 - \Psi_{ro})\,\Psi_f \tilde{rp}_t^f \tag{4.53}$$

4.2.6 Real Exchange Rate, Terms of Trade and Foreign Demand

The real exchange rate Q_t is defined as follows:

$$Q_t = \frac{S_t P_t^{f*}}{P_t} \tag{4.54}$$

The log-linear version of the real exchange rate is: $\tilde{q}_t = \tilde{s}_t + \tilde{p}_t^{f*} - \tilde{p}_t$. It is the ratio of the aggregate foreign price index to the aggregate domestic price index. An increase in the ratio implies depreciation and appreciation, otherwise.

The terms of trade Υ_t following Gali & Monacelli (2005) is:

$$\Upsilon_t = \frac{P_t^f}{P_t^h} = \frac{S_t P_t^{f*}}{P_t^h} \tag{4.55}$$

It expresses the price of imports relative to the price of domestically produced goods. The log-linear equivalent of 4.55 is: $\tilde{\Upsilon}_t = \tilde{p}_t^f - \tilde{p}_t^h$, whose first-difference yields: $\Delta\tilde{\Upsilon} = \tilde{\pi}_t^f - \tilde{\pi}_t^h$.

The domestic real price of imported refined oil can be expressed as:

$$\frac{P_t^{ro}}{P_t} = Q_t \frac{P_t^{ro*}}{P_t^{f*}} \tag{4.56}$$

Where $P_t^{ro} = S_t P_t^{ro*}$ is the domestic nominal price of refined oil, $P_t^{f*} \equiv P_t^*$ is the foreign price index and P_t^{ro*} is the foreign price of refined oil. In log-linear form, 4.56 yields: $\tilde{rp}_t^{ro} = \tilde{q}_t + \tilde{rp}_t^{ro*}$. Where domestic real price of refined oil $\tilde{rp}_t^{ro} = \tilde{p}_t^{ro} - \tilde{p}_t$ and the foreign real price of refined oil $\tilde{rp}_t^{ro*} = p_t^{ro*} - p_t^{f*}$. The foreign real price of refined oil $\tilde{rp}_t^{ro*}$ should normally evolve as an exogenous process; where $\tilde{rp}_t^{ro*} = \rho_{\tilde{rp}^{ro*}} \tilde{rp}_{t-1}^{ro*} + \varepsilon_t^{\tilde{rp}^{ro*}}$ $\varepsilon_t^{\tilde{rp}^{ro*}} \sim N(0, \sigma_{\tilde{rp}^{ro*}}^2)$. However, this is not the case, as the evolution of foreign refined oil price has been linked to that of the foreign price of crude oil, such that crude oil price shock gets transmitted to the foreign price of refined oil as shown in 4.93 later. Also, the pass-through from foreign refined oil price to domestic refined oil price will be incomplete whenever government subsidy applies.

The small open economy exports domestically produced goods and crude oil to the rest of the world. The foreign demand for domestically produced goods in the rest of the world is:

$$C_t^{h*} = \mathit{\Psi}_h^* \left(\frac{P_t^{h*}}{P_t^{f*}}\right)^{-\epsilon_h^*} C_t^* \tag{4.57}$$

Where the foreign price elasticity of demand for domestically produced goods is given by ϵ_h^*, the share of domestically produced core goods in foreign households consumption basket is given by $\mathit{\Psi}_h^*$. The export sector is modeled based on the assumption of the law of one price, implying a complete pass-through from domestic to foreign prices. Consequently, C_t^{h*} is priced in foreign market as $P_t^{h*} = \frac{P_t^h}{S_t}$ and equation 4.57 can then be re-arranged as follows:

$$C_t^{h*} = \mathit{\Psi}_h^* \left(\frac{P_t^h}{S_t P_t^{f*}}\right)^{-\epsilon_h^*} C_t^*$$

$$C_t^{h*} = \mathit{\Psi}_h^* \left(\frac{P_t^h}{P_t}\right)^{-\epsilon_h^*} \left(\frac{P_t}{S_t P_t^{f*}}\right)^{-\epsilon_h^*} C_t^*$$

$$C_t^{h*} = \Psi_h^* \left(\frac{P_t^h}{P_t}\right)^{-\epsilon_h^*} \left(\frac{1}{Q_t}\right)^{-\epsilon_h^*} C_t^* \tag{4.58}$$

This expresses foreign demand for SOE's goods as a function of the real exchange rate. Given the small open economy assumption, the share of domestically produced goods Ψ_h^* in foreign consumption basket C_t^* is negligible and preferences between domestic and foreign consumers are symmetric. Equation 4.58 can be expressed log-linearly as follows:

$$\tilde{c}_t^{h*} = -\epsilon_h^*(\tilde{p}_t^h - \tilde{p}_t - \tilde{q}_t) + \tilde{c}_t^* \tag{4.59}$$

From equation 4.46, $\tilde{\psi}_t = \tilde{s}_t + p_t^{f*} - p_t^f$. This can be expressed as:

$$\tilde{\psi}_t + p_t^f = \tilde{s}_t + p_t^{f*} \tag{4.60}$$

Given equation 4.60, we follow Monacelli (2005) to combine the log-linear versions of equations 4.10, 4.46, 4.54 and 4.55 to obtain an important relationship between the real exchange rate, the law of one price gap and the terms of trade as follows:

$$\tilde{q}_t = \tilde{\psi}_t + \tilde{\Upsilon}_t (1 - \Psi_f) \tag{4.61}$$

Equation 4.61 expresses the real exchange rate as a positive function of the law of one price gap $\tilde{\psi}_t$ and product of the terms of trade $\tilde{\Upsilon}_t$ and the share of domestically produced goods in the core consumption basket $1 - \Psi_f$. From 4.60, we can derive an expression for the nominal exchange rate as follows:

$$\tilde{s}_t = \tilde{s}_{t-1} + \tilde{\pi}_t^f - \tilde{\pi}_t^* + \tilde{\psi}_t - \tilde{\psi}_{t-1} \tag{4.62}$$

4.2.7 Imperfect International Risk Sharing and the Uncovered Interest Rate Parity

Foreign households are required to solve inter-temporal consumption, savings and labour supply problem analogous to that of domestic household, except that domestic households must face an endogenous risk premium $\digamma_t\left(\frac{S_t B_t^*}{P_t Y_t}, \epsilon_t^{\digamma}\right)$ when they participate in the international financial market. Under this condition, consumption risk is not perfectly shared between domestic and foreign households. Hence, the need to augment the equality between domestic and foreign consumption Euler equations in 4.24 and 4.25, respectively, with the risk premium $\digamma_t\left(\frac{S_t B_t^*}{P_t Y_t}, \epsilon_t^{\digamma}\right)$, as follows:

$$\frac{1 + i_t}{(1 + i_t^*)\, \digamma_t\left(\frac{S_t B_t^*}{P_t Y_t}, \epsilon_t^{\digamma}\right)} = \frac{E_t\left[\left(\frac{C_{t+1}}{C_t}\right)^{-\eta}\left(\frac{P_t}{P_{t+1}}\right)\right]}{E_t\left[\left(\frac{C_{t+1}^*}{C_t^*}\right)^{-\eta}\left(\frac{S_t P_t^*}{S_{t+1} P_{t+1}^*}\right)\right]} \tag{4.63}$$

Equation 4.63 can be solved iteratively in line with Gali & Monacelli (2005), to derive the following expression:

$$C_t = \Omega \left(Q_t \digamma_t \right)^{\frac{1}{\eta}} C_t^* \tag{4.64}$$

where Ω is a constant which represents the initial assets position, C_t is domestic consumption and C_t^* is foreign consumption. From 4.64, the ratio of marginal utility of consumption to price between domestic and foreign consumers is not equal, resulting to a relative demand gap[12] shown by $\digamma_t \neq 1$. This underlies the risk sharing incompleteness between domestic and foreign households in the model .

In log-linear form, equation 4.64 yields the following:

$$\tilde{c}_t = \frac{1}{\eta} \left(\tilde{q}_t + \tilde{\digamma}_t \right) + \tilde{c}_t^* \tag{4.65}$$

Substituting 4.61 into 4.65 results in 4.66:

$$\tilde{c}_t = \frac{1}{\eta} \left[\tilde{\psi}_t + \tilde{\Upsilon}_t \left(1 - \Psi_f \right) + \tilde{\digamma}_t \right] + \tilde{c}_t^* \tag{4.66}$$

Given equations 4.24 and 4.25, the uncovered interest rate parity (UIP) condition which shows the no-arbitrage condition in an incomplete international financial market situation can be derived as follows:

$$\frac{1}{R_t^* \digamma_t} = \left(\frac{1}{R_t} \right) \left(\frac{S_t}{E_t S_{t+1}} \right) \tag{4.67}$$

In equation 4.67, the presence of $\digamma_t$ alters the conventional interest rate parity condition into a modified version which is given in log-linear form as $\left(\tilde{i}_t - E_t \tilde{\pi}_{t+1} \right) - \left(\tilde{i}_t^* - E_t \tilde{\pi}_{t+1}^* \right) = E_t \left(\tilde{q}_{t+1} - \tilde{q}_t \right) + \tilde{\digamma}_t$. The domestic real interest rate $\tilde{r}_t = \tilde{i}_t - E_t \tilde{\pi}_{t+1}$ and the foreign real interest rate $\tilde{r}_t^* = \tilde{i}_t^* - E_t \tilde{\pi}_{t+1}^*$. Therefore, the log-linearized modified uncovered interest rate parity (UIP) condition can be written as:

$$\tilde{r}_t - \tilde{r}_t^* = E_t \left(\tilde{q}_{t+1} - \tilde{q}_t \right) + \tilde{\digamma}_t \tag{4.68}$$

The expression in 4.68 suggests that the real interest rate differential between the SOE and the foreign economy is accounted for by the expected exchange rate depreciation and the risk premium.

4.2.8 External Debt and the Risk Premium

We assume that both households and the government participate in the domestic bonds market, while only households can access the foreign bonds market. Domestic

[12]As discussed in Motyovszki (2016) and Jalali Naini & Naderian (2017)

bonds holding dynamics results to a zero net supply[13], such that $B_t = 0$. For simplicity, we assume that households do not hold foreign bonds, but issue bonds to foreigners for consumption smoothing. Consequently, the small open economy is a net borrower, such that foreign bonds holding B_t^* is positive and the household pays a premium on top of a foreign risk-free interest rate. In the circumstance, if the SOE were to be a net lender, it would earn less returns on bonds purchased from foreign issuers, as the country risk premium is priced in.

Following Schmitt-Grohe & Uribe (2003), Cavoli (2009), Garcia & Gonzalez (2013), Motyovszki (2016) and Kreptsev & Seleznev (2018), the risk premium $\digamma_t$ is influenced by the foreign debt to GDP ratio d_t (where $d_t = \frac{S_t B_t^*}{P_t Y_t} = \tilde{s}_t + \tilde{b}_t^* - \tilde{p}_t - \tilde{y}_t$) deviation from it's steady value d in log-linear form and a stochastic risk premium shock $\epsilon_t^{\digamma}$. We model the risk premium to act as a second indicator of external vulnerability, beside crude oil price, for the small open economy. The rationale for this assumption is established in Smets & Wouters (2003) and Smets *et al.* (2010) who reported that the domestic risk premium shock acted like a negative demand shock, leading to extended decline in domestic spending. In addition, a positive risk premium shock increases the cost of foreign bonds issuance; thereby constraining domestic households ability to acquire foreign debt to smooth consumption in the event of an adverse shock. The risk premium equation can be formalized in log-linear form as follows:

$$\tilde{\digamma}_t = \Phi_d \tilde{d}_t + \epsilon_t^{\digamma} \tag{4.69}$$

Where Φ_d is the elasticity parameter with respect to foreign debt to GDP ratio while $\epsilon^{\digamma}$ is the stochastic risk premium shock, assumed to approximate other influences on the risk premium. The risk premium is an increasing function of the economy's foreign debt to GDP ratio.

4.2.9 The Domestic Oil Sector

The small open economy is endowed with oil mineral reserves over which government exercises control. The representative oil firm obtains a government license and pays taxes to government. Crude oil output of the representative oil firm is exported wholly to the rest of the world. The world oil market is characterized by perfect competition; with the price of crude oil given as $P_t^{co} = S_t P_t^{co*}$. P_t^{co*} evolves as an exogenous process as follows:

$$\tilde{p}_t^{co*} = \rho_{p^{co*}} \tilde{p}_{t-1}^{co*} + \varepsilon_t^{p^{co*}} \qquad \varepsilon_t^{p^{co*}} \sim N(0, \sigma_{p^{co*}}^2) \tag{4.70}$$

[13]The domestic bonds market is always in equilibrium. Every amount borrowed by one agent (say households) is saved by the other (say the government) and vice versa.

Crude oil production Y_t^{co} requires a mix of labour and oil capital captured by a Cobb-Douglas type production function: $Y_t^{co} = Z_t^{co}\left(K_t^{co}\right)^{\gamma_{co}}\left(L_t^{co}\right)^{1-\gamma_{co}}$. Y_t^{co} is the crude oil output, Z_t^{co} is oil sector productivity, K_t^{co} is the previous period oil capital, L_t^{co} is labour supply in the oil sector and γ_{co} represents the share of oil capital in oil production.

A representative oil firm seeking to maximize net oil revenue [14] solves the following maximization problem:

$$
\begin{aligned}
& \underset{L_t^{co}}{Maximize}\, NR_t^{co} = \left[GR_t^{co} - W_t L_t^{co} - R_t^{co} K_t^{co}\right] \\
& s.t \\
& Y_t^{co} = Z_t^{co}\left(K_{t-1}^{co}\right)^{\gamma_{co}}\left(L_t^{co}\right)^{1-\gamma_{co}} \qquad (4.71)
\end{aligned}
$$

Where NR_t^{co} is net crude oil revenue, the revenue accruing to the representative oil firm after capital and labour costs have been deducted from gross crude oil revenue, GR_t^{co} (which is $P_t^{co}Y_t^{co}$). Net crude oil revenue NR_t^{co} is subject to tax[15] τ^{co} from the government and the balance $1-\tau^{co}$ is paid as returns to foreigners who provide oil sector capital in form of foreign direct investment (FDI).

Accordingly, the first order conditions (FOCs) with respect to labour and an oil capital are:

$$L_t^{co} = \left(1-\gamma_{co}\right)\frac{P_t^{co}Y_t^{co}}{W_t} \qquad (4.72)$$

$$K_t^{co} = \gamma_{co}\frac{P_t^{co}Y_t^{co}}{R_t^{co}} \qquad (4.73)$$

The law of motion for oil sector capital is as follows:

$$K_{t+1}^{co} = \left(1-\delta_{co}\right)K_t^{co} + FDI_t \qquad (4.74)$$

Where FDI_t is foreign direct investment. It evolves log-linearly as follows:

$$\tilde{fdi}_t = \rho_{fdi}\tilde{fdi}_{t-1} + (1-\rho_{fdi})\tilde{p}_t^{co*} + \varepsilon_t^{fdi} \qquad (4.75)$$

The log-linear expressions for oil sector production function, labour, interest on oil capital, oil capital and the net revenue from crude oil are as follows:

$$\tilde{y}_t^{co} = \tilde{z}_t^{co} + \gamma_{co}\tilde{k}_t^{co} + (1-\gamma_{co})\tilde{l}_t^{co}$$

[14] The representative oil producing firm is, in effect, trying to maximize government revenues since it does not make profit

[15] This captures royalties and petroleum profit tax

$$\tilde{l}_t^{co} = \tilde{p}_t^{co} + \tilde{y}_t^{co} - \tilde{w}_t$$

$$\tilde{r}_t^{co} = \tilde{p}_t^{co} + \tilde{y}_t^{co} - \tilde{k}_t^{co}$$

$$\tilde{k}_{t+1}^{co} = \frac{\overline{FDI}}{\overline{K^{co}}}(\tilde{fdi}_t) + (1-\delta_{co})\tilde{k}_t^{co}$$

$$\tilde{nr}_t^{co} = \left(1/\frac{\overline{NR^{co}}}{\overline{GR^{co}}}\right)\tilde{gr}_t^{co} - \left(\frac{\overline{WL^{co}}}{\overline{GR^{co}}}/\frac{\overline{NR^{co}}}{\overline{GR^{co}}}\right)(\tilde{w}_t + \tilde{l}_t^{co}) - \left(\frac{\overline{R^{co}K^{co}}}{\overline{GR^{co}}}/\frac{\overline{NR^{co}}}{\overline{GR^{co}}}\right)(\tilde{r}_t^{co} + \tilde{k}_t^{co})$$

Where $\tilde{z}_t^{co}$ evolves exogenously as follows:

$$\tilde{z}_t^{co} = \rho_{z^{co}}\tilde{z}_{t-1}^{co} + \varepsilon_t^{z^{co}} \qquad \varepsilon_t^{z^{co}} \sim N(0, \sigma_{z^{co}}^2) \tag{4.76}$$

Given that oil output Y_t^{co} is completely exported to the rest of the world, such that $Y_t^{co} = C_t^{hco*}$, the foreign demand for the SOE's crude oil is as follows:

$$C_t^{hco*} = \Psi_{co}^* \left(\frac{P_t^{co*}}{P_t^{f*}}\right)^{-\epsilon_{co}^*} C_t^{co*} \tag{4.77}$$

Following steps used for equations 4.57 - 4.58 earlier, equation 4.77 can be re-written as follows:

$$C_t^{hco*} = \Psi_{co}^* \left(\frac{P_t^{co}}{P_t}\right)^{-\epsilon_{co}^*} \left(\frac{1}{Q_t}\right)^{-\epsilon_{co}^*} C_t^{co*} \tag{4.78}$$

Where the foreign price elasticity of demand for domestically produced crude oil is given by ϵ_{co}^* and the share of domestically produced crude oil in total foreign crude oil consumption is given by Ψ_{co}^*. Given our small open economy assumption, the share of domestically produced crude oil in total foreign oil consumption basket C_t^{co*} is negligible. Both foreign crude oil price $P_t^{co*}$and foreign oil consumption C_t^{co*} are assumed to evolve exogenously. The log-linear form of 4.78 is:

$$\tilde{c}_t^{hco*} = -\epsilon_{co}^*(\tilde{p}_t^{co} - \tilde{p}_t - \tilde{q}_t) + \tilde{c}_t^{co*} \tag{4.79}$$

4.2.10 The Labour Market

The labour market is assumed to be competitive and this ensures wage equality across the two production sectors. From equations 4.32 and 4.72, $L_t^h = (1 - \vartheta_h)\left(\frac{NMC_t}{W_t}\right)^{\omega_h} Y_t^h$ and $L_t^{co} = (1-\gamma_{co})\frac{P_t^{co}Y_t^{co}}{W_t}$ in the domestic goods and oil producing sectors, respectively. We can re-write these equations as follows:

$$W_t = NMC_t^h \left(\frac{(1-\vartheta_h)}{L_t^h} Y_t^h \right)^{\frac{1}{\omega_h}}$$

$$W_t = (1-\gamma_{co}) \left(\frac{P_t^{co} Y_t^{co}}{L_t^{co}} \right)$$

Equalizing the two wage expressions, yields:

$$W_t = \left(\frac{(NMC_t^h) L_t^{co}}{(1-\gamma_{co})(P_t^{co} Y_t^{co})} \right) \left(\frac{(1-\vartheta_h)}{L_t^h} Y_t^h \right)^{\frac{1}{\omega_h}} \tag{4.80}$$

The equilibrium wage rate in log-linear form will be:

$$\tilde{w}_t = n\tilde{m}c_t^h + \tilde{l}_t^{co} - \tilde{p}_t^{co} - \tilde{y}_t^{co} + \frac{1}{\omega_h} \left[(1-\vartheta_h)\tilde{y}_t^h - \tilde{l}_t^h \right]$$

4.2.11 Government

Government is assumed to consume both domestically produced and imported goods. It undertakes the importation of refined oil and sells it to households and domestic firms. Thus, refined oil subsidy constitutes parts of government expenditure. The quantum of subsidy depends on foreign oil market dynamics and the degree of its intervention in the sector.

4.2.11.1 Government Demand

The government consumption basket includes domestically produced goods and imports as follows:

$$G_t = [(1-\Psi_g)^{\frac{1}{\upsilon_g}} (G_t^h)^{\frac{\upsilon_g - 1}{\upsilon_g}} + (\Psi_g)^{\frac{1}{\upsilon_g}} (G_t^f)^{\frac{\upsilon_g - 1}{\upsilon_g}}]^{\frac{\upsilon_g}{\upsilon_g - 1}} \tag{4.81}$$

Where Ψ_g and $1-\Psi_g$ are weights of imported and domestic goods, respectively, in government consumption basket. υ_g is the elasticity of substitution between the two goods variety in government consumption bundle. Applying the CES consumption aggregator and minimizing expenditure, government demand functions for the two goods categories becomes:

$$G_t^h = 1 - \Psi_g \left(\frac{P_t^h}{P_t^c} \right)^{-\upsilon_g} G_t \tag{4.82}$$

$$G_t^f = \Psi_g \left(\frac{P_t^f}{P_t^c} \right)^{-\upsilon_g} G_t \tag{4.83}$$

The corresponding log-linear equilibrium government demand functions for core domestic and import goods are as follows:

$$\tilde{g}_t^h = \upsilon_g \Psi_g \tilde{\Upsilon}_t + \tilde{g}_t$$

$$\tilde{g}_t^f = -\upsilon_g (1 - \Psi_g) \tilde{\Upsilon}_t + \tilde{g}_t$$

The price index for government consumption expenditure is expressed by:

$$P_t^c = [(1 - \Psi_g)(P_t^h)^{1-\upsilon_g} + \Psi_g (P_t^f)^{1-\upsilon_g}]^{\frac{1}{1-\upsilon_g}} \tag{4.84}$$

Consequently, the small open economy's government minimum total consumption expenditure will be:

$$P_t^h G_t^h + P_t^f G_t^f = P_t^c G_t \tag{4.85}$$

Fiscal behaviour is assumed to follow an exogenous process as follows:

$$\tilde{g}_t = \rho_g \tilde{g}_{t-1} + \epsilon_t^g \qquad \epsilon_t^g \sim N(0, \sigma_g^2) \tag{4.86}$$

4.2.11.2 Refined Oil Price

We assume government intervenes to smooth the domestic price of refined oil, as is the case in many net oil exporting developing and emerging economies. Consequently, the domestic refined oil price is modeled as a rule following Bouakez *et al.* (2008) and Allegret & Benkhodja (2015), as a convex combination of the immediate past period's domestic price and the prevailing foreign price of refined oil expressed in domestic currency as follows:

$$P_t^{ro} = \varsigma P_{t-1}^{ro} + (1 - \varsigma)\, S_t P_t^{ro*} \tag{4.87}$$

Where $\varsigma \in (0, 1)$ is the oil subsidy indicator and can vary based on the extent to which government is intervening in the downstream sector of the oil industry. The foreign price of refined oil is $S_t P_t^{ro*}$ while the domestic pump price of refined oil is P_t^{ro}. If the subsidy indicator parameter $\varsigma = 1$, the degree of intervention is total and there is no pass-through from foreign price of refined oil to the domestic price; ensuring that the domestic price is fixed at the old level and the differential is completely picked up by government subsidy, Θ_t. If, however, $\varsigma = 0$, then there is no subsidy, domestic refined oil price will reflect fully foreign dynamics of refined oil price and as such there will be a complete pass-through. We will consider three (3) subsidy experiments, namely: (a) full subsidy, (b) zero subsidy and (c) partial subsidy at a fraction of 0.5.

The refined oil pricing rule, though arbitrary since it is not derived from an explicit optimization of government behaviour; it is, however, used to reflect the practice in many emerging small open economies, where domestic price of refined oil prices are based on ad-hoc pricing templates intended to smooth oil price volatility. The pricing rule is also useful for showing that fiscal intervention through oil subsidy may not permit complete oil price pass-through. Also, the fiscal commitment to an oil pricing rule may be a good anchor for agents expectations about refined oil price Bouakez *et al.* (2008). The oil pricing rule can potentially generate an increase or a decrease in oil subsidy depending on the nature of the oil price shock and the size of the subsidy parameter. The equation for subsidy is as follows:

$$\Theta_t = S_t P_t^{ro*} - P_t^{ro} \tag{4.88}$$

In real term, it can be expressed log-linearly as:

$$\tilde{\theta}_t = \frac{\overline{QP^{ro*}}}{\overline{\Theta}}(\tilde{q}_t + \tilde{p}_t^{ro*}) - \frac{\overline{RP^{ro}}}{\overline{\Theta}}(r\tilde{pro}_t) \tag{4.89}$$

4.2.11.3 Government Budget Constraint

Government revenue is sourced through receipts from lump-sum tax τ_t levied on households and tax on oil firm's net crude oil proceeds $\tau^{co} NR_t^{co}$ and government expenditure includes spending on domestic and foreign goods $P_t^h G_t^h$ and $P_t^f G_t^f$, respectively; and refined oil subsidy[16] payments Θ_t applied on total refined oil imports M_t^{ro}.

Government budget constraint is expressed as follows:

$$\tau^{co}\left(\frac{NR_t^{co}}{P_t}\right) + \tau_t = G_t^h + G_t^f + \Theta_t M_t^{ro} \tag{4.90}$$

Where $M_t^{ro} = C_t^{ro} + RO_t^h$ with C_t^{ro} and RO_t^h being refined oil consumed by households and domestic firms, respectively. The log-linearized overall government budget constraint is obtained as follows:

[16] Government pays the difference between the foreign price of refined oil and the domestic price.

$$\tilde{g}_t = \left(\frac{\overline{\tau^{co}NR^{co}/P}}{\overline{G}}\right)(\tilde{nr}^{co}) + \left(\frac{\overline{\tau}}{\overline{G}}\right)\tilde{\tau}_t$$
$$- \left[\left(\frac{\overline{\Theta M^{ro}}}{\overline{G}}\right)(\tilde{q}_t + \tilde{\Theta}_t + \tilde{m}_t^{ro})\right]$$
$$- \left(\frac{\overline{G^h}}{\overline{G}}\right)\tilde{g}^h - \left(\frac{\overline{G^f}}{\overline{G}}\right)\tilde{g}^f \tag{4.91}$$

Where τ_t evolves log-linearly according to the following fiscal rule:

$$\tilde{\tau}_t = \rho_\tau \tilde{\tau}_{t-1} + (1-\rho_\tau)\left(\chi_1\tilde{d} - \chi_2(\tilde{p}_t^{co} + \tilde{y}_t^{co} - \tilde{p}_t)\right) + \epsilon_t^\tau \tag{4.92}$$

The expression for lump-sum tax include a smoothing component (ρ_τ) and its sensitivity to the economy's debt to GDP ratio (χ_1) and crude oil revenues (χ_2). Many emerging and developing oil producing economies tend to intensify tax efforts whenever the threat of a debt overhang looms, and when external borrowing conditions become tighter. They tend to relax their non-oil tax revenue efforts whenever the oil sector is booming (Tijerina-Guajardo & Pagán, 2003).

4.2.12 Interaction between Crude and Refined Oil Prices

We propose a relationship to account for the relationship between foreign crude oil price and foreign refined oil price based on empirical evidence[17]. This relationship evolves log-linearly as follows:

$$\tilde{p}_t^{ro*} = \zeta_{p^{co*}}\tilde{p}_{t-1}^{co*} + (1-\zeta_{p^{ro*}})\tilde{va}_t^{ro*} + \epsilon_t^{ro*} \tag{4.93}$$

Equation 4.93 show that foreign price of refined oil depends on last period's foreign price of crude oil $\tilde{p}_{t-1}^{co*}$ and the current period's value added costs $\tilde{va}_t^{ro*}$, which may include refining cost, foreign tax on refined oil and distribution or marketing costs. The relationship between previous period foreign price of crude oil and the current period foreign price of refined oil is governed by $\zeta_{p^{co*}}$ while ϵ_t^{ro*} is an exogenous shock. This pricing rule allows us to establish a nexus between the foreign prices of the crude oil and the refined version (petroleum). The characterization can assist a net oil exporting developing economy to gauge the net real value derivable from its oil endowments and underscore the need to maximize the benefits of oil domestically. Such a country too, can gain insight on the extent to which it is vulnerable to oil-related adverse shocks. Foreign refined oil value added cost $\tilde{va}_t^{ro*}$ is treated as an auto-regressive process as follows:

[17]Data obtained from the US Energy Information Administration

$$\tilde{va}_t^{ro*} = \rho_{va^{ro*}} \tilde{va}_{t-1}^{ro*} + \epsilon_t^{va^{ro*}} \tag{4.94}$$

4.2.13 Aggregation and Market Clearing

4.2.13.1 Goods Market

In order to satisfy the aggregate market clearing condition, gross domestic product (GDP) must equal consumption of domestic goods by households, government and foreigners; consumption of SOE crude oil by foreigners; consumption of core imports by households and government and consumption of refined oil imports by households and non-oil firms.

$$Y_t = Y_t^h + X_t - M_t \tag{4.95}$$

Core domestic goods are consumed by domestic households, foreign households and the government, giving rise to the following:

$$Y_t^h = C_t^h + C_t^{h*} + G_t^h \tag{4.96}$$

All crude oil produced domestically is consumed in the rest of the world, such that:

$$Y_t^{hco} = C_t^{hco*} \tag{4.97}$$

Total import comprises imported core goods M_t^f and imported refined oil M_t^{ro}. Imported core goods are consumed by households C_t^f and government G_t^f while imported refined oil is consumed by households C_t^{ro} and used by domestic firms as input RO_t^h, giving rise to the following import equations:

$$M_t = M_t^f + M_t^{ro} \tag{4.98}$$

$$M_t^f = C_t^f + G_t^f$$

$$M_t^{ro} = C_t^{ro} + RO_t^h$$

Total exports X_t is the sum of core exports and crude oil exports and can be represented as follows:

$$X_t = C_t^{h*} + Y_t^{hco} \tag{4.99}$$

Equations 4.100 - 4.105 below represent the log-linearized open economy aggregate IS curve, aggregate output and its components, respectively:

$$\tilde{y}_t^h = \frac{\overline{C^h}}{\overline{Y^h}}\tilde{c}_t^h + \frac{\overline{C^{h*}}}{\overline{Y^h}}\tilde{c}_t^{h*} + \frac{\overline{G^h}}{\overline{Y^h}}\tilde{g}_t^h \tag{4.100}$$

$$\tilde{y}_t = \frac{\overline{C}}{\overline{Y}}\tilde{c}_t + \frac{\overline{X}}{\overline{Y}}\tilde{x}_t - \frac{\overline{M}}{\overline{Y}}\tilde{m}_t \tag{4.101}$$

$$\tilde{x}_t = \frac{\overline{C^{h*}}}{\overline{X}}\tilde{c}_t^{h*} + \frac{\overline{C^{hco*}}}{\overline{X}}\tilde{c}_t^{hco*} \tag{4.102}$$

$$\tilde{m}_t = \frac{\overline{M^f}}{\overline{M}}\tilde{m}_t^f + \frac{\overline{M^{ro}}}{\overline{M}}\tilde{m}_t^{ro} \tag{4.103}$$

$$\tilde{m}_t^f = \frac{\overline{C^f}}{\overline{M^f}}\tilde{c}_t^f + \frac{\overline{G^f}}{\overline{M^f}}\tilde{g}_t^f \tag{4.104}$$

$$\tilde{m}_t^{ro} = \frac{\overline{C^{ro}}}{\overline{M^{ro}}}\tilde{c}_t^{ro} + \frac{\overline{RO^h}}{\overline{M^{ro}}}\tilde{ro}_t^h \tag{4.105}$$

4.2.13.2 Bonds Market

Aggregate bonds is the sum of domestic and foreign bonds ($B_t^{agg} = B_t + B_t^*$). However, domestic bonds are assumed to be in net zero supply such that $B_t = 0$; and foreign bonds B_t^* are issued by domestic households while for simplicity, domestic households do not subscribe to foreign issued bonds.[18] Our earlier bonds assumption results to a bonds clearing condition which equate aggregate bonds holding to total foreign bonds holding as follows:

$$B_t^{agg} = B_t^* \tag{4.106}$$

4.2.13.3 Labour Market

The labour market clearing condition results from the equality of the sum of employment in the non-oil and oil sectors to the total labour supply in the economy. It is represented as follows:

$$L_t = L_t^h + L_t^{co} \tag{4.107}$$

We derive the equilibrium dynamics in the labour market by linearizing 4.107, and substituting out the log-linear versions of 4.32 and 4.72 in same; together with

[18]Were agents in SOE allowed to buy foreign-issued bonds, this will count as part of foreign assets, the bit of the model we have abstracted from

the corresponding steady state ratios as follows:

$$\tilde{l}_t = \left(\frac{\overline{L^h}}{\overline{L}}\right) \tilde{l}_t^h + \left(\frac{\overline{L^{co}}}{\overline{L}}\right) \tilde{l}_t^{co} \tag{4.108}$$

Where $\frac{\overline{L^{co}}}{\overline{L}}$ and $\frac{\overline{L^h}}{\overline{L}}$ are the steady state ratios associated with labour in the oil and non-oil sectors to total labour.

4.2.14 External Debt and Current Account Dynamics

The current account equates foreign debt service adjusted by the country risk premium[19] to the sum of total trade balance and foreign debt holdings. This can be presented as follows:

$$\left(\digamma_t \left(\frac{S_t B_t^*}{P_t Y_t}, \epsilon_t^{\digamma}\right) R_t^*\right) S_t B_{t+1}^* = S_t B_t^* + P_t^x X_t - P_t^m M_t \tag{4.109}$$

Where $P_t^x X_t$ and $P_t^m M_t$ are the nominal exports and imports, respectively. These identities are further defined as follows:

$$P_t^x X_t = S_t P_t^{h*} C_t^{h*} + S_t P_t^{co*} Y_t^{hco*} \tag{4.110}$$

$$P_t^m M_t = P_t^f C_t^f + P_t^f G_t^f + P_t^{ro} C_t^{ro} + P_t^{ro} RO_t^h \tag{4.111}$$

Expressed in log-linear form[20], 4.109 becomes:

$$\tilde{b}_t^* = \frac{1}{\beta} \tilde{b}_{t-1}^* + n\tilde{x}_t - fdir_t + \frac{\overline{NX/PY}}{\beta - 1} (\tilde{r}_{t-1}^* + \tilde{\digamma}_{t-1} + \triangle \tilde{q}_t - \tilde{\pi}_t) \tag{4.112}$$

Where $n\tilde{x}_t$ is the log-linearized net export expressed as follows:

$$n\tilde{x}_t = \tilde{x}_t - \tilde{m}_t \tag{4.113}$$

$fdir_t$ is the returns received by oil sector foreign direct investors and it evolves according to the following rule:

$$fdir_t = 1 - \tau^{co}(nr_t^{co}) \tag{4.114}$$

[19] Although we assume foreign bonds issuance is limited to domestic households, government liability is implied as these bonds are often backed by the full faith of government.

[20] In line with Bergholt (2014)

4.2.15 Monetary Policy

The model is closed with a Taylor (1993)-type interest rate rule augmented with the exchange rate. The exchange is under some degree of monetary policy watch in many emerging SOEs. The central bank is assumed to react to deviation of output, inflation and the exchange rate from their steady state values. It is common in the literature to include the exchange rate in the monetary policy rules for small open economy models[21]. The generalized Taylor rule, in addition to output and the exchange rate, features three important inflation variants, namely: aggregate inflation π_t, domestic inflation π_t^h and core inflation π_t^c.

$$\tilde{i}_t = \tilde{i}_{t-1}^{\rho_i} \left[\left(\frac{Y_t}{\bar{Y}}\right)^{\varpi_1} \left(\frac{\pi_t}{\bar{\pi}}\right)^{\varpi_2} \left(\frac{\pi_t^h}{\bar{\pi}^h}\right)^{\varpi_3} \left(\frac{\pi_t^c}{\bar{\pi}^c}\right)^{\varpi_4} \left(\frac{S_t/S_{t-1}}{\bar{S}}\right)^{\varpi_5} \right]^{1-\rho_r} \tag{4.115}$$

The log-linear expression for the above generalized monetary policy rule is as follows:

$$\tilde{i}_t = \rho_i \tilde{i}_{t-1} + (1-\rho_i)\left(\varpi_1 \tilde{y}_t + \varpi_2 \tilde{\pi}_t + \varpi_3 \tilde{\pi}_t^h + \varpi_4 \tilde{\pi}_t^c + \varpi_5 \Delta \tilde{s}_t\right) + \epsilon_t^i \tag{4.116}$$

Where ϖ_1, ϖ_2, ϖ_3, ϖ_4 and ϖ_5 are weights associated with output, aggregate inflation, domestic inflation, core inflation and the exchange rate, respectively in the generalized Taylor rule. The size of each weight reflects the relative importance of the corresponding variables in the monetary policy reaction function. ρ_i is the smoothing parameter and it captures policy inertia or policy history dependence (Woodford, 2003) while ϵ_t^i is the monetary policy shock. From the generalized Taylor rule in 4.116, the following alternative policy rules are assumed:

$$\tilde{i}_t = \rho_i \tilde{i}_{t-1} + (1-\rho_i)(\varpi_1 \tilde{y}_t + \varpi_2 \tilde{\pi}_t) + \epsilon_t^i \tag{4.117}$$

$$\tilde{i}_t = \rho_i \tilde{i}_{t-1} + (1-\rho_i)\left(\varpi_1 \tilde{y}_t + \varpi_3 \tilde{\pi}_t^h\right) + \epsilon_t^i \tag{4.118}$$

$$\tilde{i}_t = \rho_i \tilde{i}_{t-1} + (1-\rho_i)(\varpi_1 \tilde{y}_t + \varpi_4 \tilde{\pi}_t^c) + \epsilon_t^i \tag{4.119}$$

$$\tilde{i}_t = \rho_i \tilde{i}_{t-1} + (1-\rho_i)(\varpi_1 \tilde{y}_t + \varpi_5 \Delta \tilde{s}_t) + \epsilon_t^i \tag{4.120}$$

Equations (4.117 - 4.120) represents an aggregate inflation targeting rule, a do-

[21]See Gali & Monacelli (2005), De Paoli (2009), Senbeta (2011), Hove *et al.* (2015), Allegret & Benkhodja (2015), etc

mestic inflation targeting rule, a core inflation targeting rule and a real exchange rate targeting rule, respectively. Under all the four policy regimes, the policy maker exhibit permanent interest in interest rate smoothing and aggregate output stabilization; and combines these with one of aggregate inflation (headline), domestic inflation and core inflation.

4.2.16 The Foreign Economy

Foreign variables evolve exogenously as follows:

$$\tilde{i}_t^* = \rho_{i^*}\tilde{i}_{t-1}^* + \epsilon_t^{i*} \tag{4.121}$$

$$\tilde{c}_t^* = \rho_{c*}\tilde{c}_{t-1}^* + \epsilon_t^{c*} \tag{4.122}$$

$$\tilde{c}_t^{co*} = \rho_{c^{co*}}\tilde{c}_{t-1}^{co*} + \epsilon_t^{c_{co*}} \tag{4.123}$$

$$\tilde{\pi}_t^* = \rho_{\pi*}\tilde{\pi}_{t-1}^* + \epsilon_t^{\pi*} \tag{4.124}$$

$$\tilde{p}_t^{f*} = \rho_{p^{f*}}\tilde{p}_{t-1}^{f*} + \epsilon_t^{p^{f*}} \tag{4.125}$$

$$\tilde{p}_t^{co*} = \rho_{p^{co*}}\tilde{p}_{t-1}^{co*} + \varepsilon_t^{p^{co*}} \tag{4.126}$$

4.3 Parameters, Solution and Simulation

The general equilibrium solution of the model is characterized by the sequences of equilibrium conditions satisfying economic agents first order conditions, market clearing conditions, the monetary policy rule, the refined oil pricing rule, the lump-sum tax rule, the government budget constraint, the external debt equation, the risk premium equation, and shocks. The model solution is up to a second-order approximation around a deterministic steady state level where all variables are constant. Parameter values are calibrated in line with standard small open economy DSGE literature while steady state ratios matches stylized features of a net oil exporting emerging economy. Tables 4.1 and 4.2 below contain parameters and steady state ratios characterizing the model, respectively:

Parameter	Description	Value
Ψ_{ro}	Share of refined oil in HHs consumption	0.25
ν	Elasticity of subst. btw. core and oil consumption	0.2
β	Discount Factor	0.96
ϖ	Elasticity of subst. within group in core consumption	8
Ψ_f	Share of imported core goods in HHs consumption	0.35
η	Relative risk aversion coefficient	1
ϱ	Elasticity of the marginal dis-utility of labour	6
ω^h	Domestic firm's factor subst. btw. refined oil and labour	0.5
ϑ_h	Refined oil weight in domestic firm's production function	0.3
ϵ_h	Elasticity of demand for domestic good variety	1
θ^h	Stickiness parameter for domestic good	0.75
θ^f	Stickiness parameter for imports	0.60
ϵ_h^*	Foreign elasticity of demand for domestic goods	1
$\rho_{p^{co*}}$	Foreign crude oil price persistence	0.88
γ_{co}	Capital share in crude oil production	0.65
δ_{co}	Oil capital depreciation rate	0.025
ϵ_{co}^*	Foreign elasticity of demand for SOE's crude oil	1
υ_g	Elasticity of subst. for govt. consumption variety	10
Ψ_g	Core imports weight in government consumption	0.35
$\rho_{z^{co}}$	Crude oil productivity shock persistence	0.85
ρ_{z^h}	Domestic good productivity shock persistence	0.80
	Full subsidy indicator	1
ς	Partial subsidy indicator	0.5
	Zero subsidy indicator	0
ρ_τ	Lump sum tax shock persistence	0.85
χ_1	Tax sensitivity to foreign debt GDP ratio	0.60
χ_2	Tax sensitivity to crude oil revenue	0.95
$\rho_{va^{ro*}}$	Foreign refined oil value added cost shock persist.	0.75
Φ_d	Risk premium elasticity wrt. debt/GDP ratio	0.0001
$\rho_{p^{f*}}$	Foreign core goods price shock persistence	0.85
ρ_i	Taylor Rule smoothing parameter	0.75
ϖ_1	Output weight in the Taylor rule	0.5
ϖ_2	CPI Inflation weight in Taylor rule	1.5
ϖ_3	Core Inflation weight in the Taylor rule	1.5
ϖ_4	Oil Inflation weight in the Taylor rule	1.5
ϖ_5	Exchange rate weight in the Taylor rule	0.25
ρ_{i^*}	Foreign Interest rate shock persistence	0.85
ρ_{c*}	Foreign core consumption shock persistence	0.90
$\rho_{c^{co*}}$	Foreign oil consumption shock persistence	0.85
$\rho_{\pi*}$	Foreign inflation shock persistence	0.85
$\zeta_{p^{co*}}$	Refined oil price dependence on past crude oil price	0.90
τ^{co}	Tax on net crude oil revenue	0.75
ρ_{fdi}	FDI persistence parameter	0.55

Table 4.1: Model Parameters

The discount factor β is set at 0.96 implying that steady state real interest is in the neighbourhood of 3% annually. The relative risk aversion parameter η is calibrated as 1, in line with Steinbach *et al.* (2009)'s estimate for South Africa, a commodity exporting SOE. The elasticity of the marginal dis-utility of labour ϱ is set at 6 based on Alpanda *et al.* (2010). The shares of refined oil Ψ_{ro}, core imports Ψ_f and domestic goods $1 - \Psi_f$ in households consumption basket, are 0.25, 0.35 and 0.65; respectively. These estimates are based on refined oil and core goods imports data for Nigeria. The shares of core imports Ψ_g and domestic goods $1 - \Psi_g$ in government consumption corresponds to those of the households at 0.35 and 0.65, respectively. The elasticity of substitution between core and oil consumption ν, the elasticity of substitution between imported core and domestic goods ϖ, and the elasticity of substitution for government consumption variety υ_g are 0.2, 8 and 10, respectively (Hove *et al.*, 2015). The domestic firm's factor substitution parameter ω^h is 0.5 while refined oil weight in domestic production ϑ_h is 0.3 (Romero, 2008). The demand elasticity for domestic goods variety ϵ_h is 1, stickiness parameters for domestic goods θ^h and imports θ^f are set at 0.75 and 0.60, respectively based on Christiano *et al.* (2005) and Gali & Monacelli (2005); while both foreign elasticity of demand for domestic core goods ϵ_h^* and crude oil ϵ_{co}^* are calibrated to 1.

The capital share in crude oil production γ_{co} and oil capital depreciation rate δ_{co} are set at 0.65 and 0.025, respectively. The foreign crude oil price shock persistence $\rho_{p^{co*}}$, the foreign refined oil value added cost shock persistence $\rho_{va^{ro*}}$ and the foreign core goods price persistence $\rho_{p^{f*}}$ are calibrated to 0.88, 0.75 and 0.85; respectively (Hove *et al.*, 2015). We set values for the foreign oil consumption shock persistence $\rho_{c^{co*}}$, foreign core consumption shock persistence ρ_{c*}, foreign interest rate shock persistence ρ_{i^*} and foreign inflation shock persistence $\rho_{\pi*}$ and the refined oil dependence on previous period crude oil price at 0.85, 0.90, 0.85, 0.85 and 0.90; respectively. The tax rate τ^{co} on net crude oil revenue is 0.75, the oil sector foreign direct investment shock persistence parameter ρ_{fdi} is 0.55, and the risk premium elasticity with respect to external debt to GDP ratio is 0.0001 in line with Schmitt-Grohe & Uribe, 2003. The domestic oil ρ_{z^h} and non-oil $\rho_{z^{co}}$ sectors productivity shock persistence are 0.85 and 0.80, respectively; while values for lump-sum tax shock persistence ρ_τ, and tax sensitivities to foreign debt to GDP ratio χ_1 and oil revenue χ_2 are 0.85, 0.60 and 0.95; respectively (Santacreu, 2005 and Alpanda *et al.*, 2010).

The smoothing parameter ρ_i in the Taylor rule, following Ortiz & Sturzenegger (2007), is set at 0.75. Following Steinbach *et al.* (2009) and Zeufack *et al.* (2016), our monetary policy parameters in the generalized Taylor rule ϖ_1, ϖ_2, ϖ_3, ϖ_4 and ϖ_5 are set at 0.5, 1.5, 1.5, 1.5 and 0.25; respectively for output, headline inflation, core inflation, oil inflation and the real exchange rate. The Taylor rule type that incorporate exchange rate element is usually envisaged for small open, emerging markets and developing economies (Mishkin, 2007 and Taylor, 2001). The inclusion of an inflation measure that reflect oil price movement in the Taylor rule captures the keen attention usually given to oil price developments in central banks of oil-dependent emerging economies. The Taylor principle requires that weights assigned to any measure of inflation should be greater than 1, to capture monetary policy's aggressive response to inflation. This is also required for the model solution (Taylor, 1993).

Ratio	Description	Value
$\frac{\overline{C}}{\overline{Y}}$	Ratio of domestic consumption to total output	0.85
$\frac{\overline{G^h}}{\overline{Y^h}}$	Ratio of government consumption of domestic goods to total	0.05
$\frac{\overline{X}}{\overline{Y}}$	Ratio of total exports to total output	0.15
$\frac{\overline{M}}{\overline{Y}}$	Ratio of total imports to total output	0.10
$\frac{\overline{C^{h*}}}{\overline{X}}$	Ratio of core export to total exports	0.10
$\frac{\overline{C^{hco*}}}{\overline{X}}$	Ratio of crude oil exports to total exports	0.90
$\frac{\overline{M^f}}{\overline{M}}$	Ratio of core imports to total imports	0.85
$\frac{\overline{M^{ro}}}{\overline{M}}$	Ratio of refined oil imports to total imports	0.15
$\frac{\overline{C^f}}{\overline{M^f}}$	Household share of core imports consumption	0.85
$\frac{\overline{G^f}}{\overline{M^f}}$	Government share of core imports consumption	0.15
$\frac{\overline{C^{ro}}}{\overline{M^{ro}}}$	Household share of imported refined oil to total	0.75
$\frac{\overline{RO^h}}{\overline{M^{ro}}}$	Firms share of imported refined oil to total	0.25
$\frac{\overline{\Theta M^{ro}}}{\overline{G}}$	SS ratio of oil subsidy to total government expenditure	0.45
$\frac{\overline{\tau^{co} NR^{co}}}{\overline{G}}$	SS ratio of govt. net crude oil revenue to govt. expenditure	0.90
$\frac{\overline{T}}{\overline{G}}$	SS ratio of lump-sum tax to government expenditure	0.10
$\frac{\overline{G^h}}{\overline{G}}$	SS ratio of gov. spending on home goods to total govt. exp.	0.30
$\frac{\overline{G^f}}{\overline{G}}$	SS ratio of gov. spending on imports to total govt. exp.	0.25
$\frac{\overline{L^h}}{\overline{L}}$	SS ratio of non-oil sector employment to total employment	0.85
$\frac{\overline{L^{co}}}{\overline{L}}$	SS ratio of oil sector employment to total employment	0.15
$\frac{\overline{NX}}{\overline{Y}}$	SS ratio of net exports to total output	0.05
$\frac{\overline{NR^{co}}}{\overline{GR^{co}}}$	SS ratio of net crude oil revenue to gross crude oil revenue	0.80
$\frac{\overline{WL^{co}}}{\overline{GR^{co}}}$	SS ratio of oil sector labour cost to gross crude oil revenue	0.05
$\frac{\overline{R^{co}K^{co}}}{\overline{GR^{co}}}$	SS ratio of oil sector capital cost to gross crude oil revenue	0.15
$\frac{\overline{FDI}}{\overline{K^{co}}}$	SS ratio of FDI to oil capital	0.45
$\overline{d} = \frac{\overline{SB^*}}{\overline{PY}}$	SS ratio of external debt to GDP	0
$\frac{\overline{\Theta M^{ro}}}{\overline{G}}$	SS ratio of refined oil subsidy to total gov. expenditure	0.45
$\frac{\overline{QP^{ro*}}}{\overline{\Theta}}$	SS ratio of unregulated real refined oil price to subsidy	3.33
$\frac{\overline{RP^{ro}}}{\overline{\Theta}}$	SS ratio of subsidized refined oil price to subsidy	2.33

Table 4.2: Model Steady State Ratios

Using Nigerian data[22] sourced from the International Financial Statistics (IFS) and the Nigerian Bureau of Statistics (NBS) and the Central Bank of Nigeria (CBN), we obtain twenty five steady state ratios as shown in Table 4.2. The model is solved in Dynare, utilizing the Blanchard & Khan (1980) procedure and we simulate a 10 percent negative oil price shock before performing an optimization exercise on the the coefficients of each alternative Taylor rule specifications under three subsidy or pass-through assumptions subject to the model's Philips Curve equations.

[22]The country is a good example of a net oil exporting country described in our model setup

4.4 Results

A negative crude oil price shock is simulated under three alternative fiscal regimes and four possible monetary policy frameworks popular in policy circles. The first fiscal regime implements full oil subsidy which does not allow any pass-through from foreign oil price to the domestic price. The second fiscal regime implements partial oil subsidy, allowing for incomplete pass-through to domestic price of refined oil; while the third regime does not allow for any oil subsidy, thus permitting a complete pass-through from foreign price of refined oil. Each fiscal intervention is tested under the four alternative monetary policy settings, namely: (i) headline inflation targeting (HIT), (ii) core inflation targeting (CIT), (iii) oil inflation targeting (OIT); and (iv) exchange rate targeting (ERT). The shock is expected to set off responses from twenty macroeconomic variables, including: headline inflation, core inflation, oil inflation, risk premium, aggregate consumption, aggregate output, crude oil output, non-oil output, interest rate, real exchange rate, government consumption, refined oil consumption, refined oil in domestic production, external debt-to-GDP ratio, non-oil employment, oil employment, oil capital, foreign direct investment, real wage and oil subsidy over a forty period horizon. The impulse responses of the variables are presented and analyzed following the negative oil price shock. The macroeconomic responses depicted by the various impulse-response functions will reflect the dynamic sensitivity of the economy to the shock, under different monetary and fiscal policy considerations.

4.4.1 Oil Price shock under alternative monetary policy strategies and a full subsidy regime (zero pass-through)

In figures 4.2 and 4.3 below, we present the impulse responses generated following the impact of a ten percent negative shock to oil price on selected macroeconomic variables under four alternative monetary policy rules, assuming a full subsidy regime or a zero percent foreign oil price pass-through. A full subsidy regime assumes a fiscal environment where government insulates the domestic economy from fluctuations in the price of imported refined oil. If this policy is effective, households and firms will not be impacted by the shock. As a result, agents will be indifferent to both positive and negative movements in oil prices.

Our result indicates that both headline and core inflation would rise marginally, while oil inflation falls by a significant percentage points around period 2. The oil shock impacts inflation via income and exchange rate channels. The income effect sets in as oil output (export) shrinks and aggregate income falls. Inflationary pressure mounts as aggregate output declines. This reflects the inflation component of the oil price-induced stagflation, given that aggregate output declined on impact while headline and core inflation rises after a period lag. In addition, the significant negative effect of the shock on government revenue [23] leads to a fall in government consumption. Exchange rate channel on the other hand, operates as foreign exchange earnings from oil receipts plummet and imports financing becomes more challenging as exchange rate volatility kicks in. Consequently, aggregate consumption declines, affecting both imported and domestic goods consumed by government and households; as inflationary pressures mount in the economy.

The shock exposes households to additional tax burden from a government determined to augment declining oil tax revenue by raising lump-sum tax and borrowing more domestically. Higher lump-sum tax reduces households disposable income and thus, constrains their capacity to maintain the pre-shock consumption level. At this point, households willing to smooth consumption through foreign debt will experience higher borrowing costs as the economy's risk premium goes up. The higher risk premium is caused by higher external debt to GDP ratio and investor concerns about debt sustainability, in addition to the other prevailing macroeconomic risks. Increased risk premium acts like an aggregate demand shock, thus amplifying the effects of the economic slump.

The negative crude oil price shock precipitates a marked contraction in oil output. The crude oil output contraction can be linked directly to the movement of productive resources away from the oil sector given that both marginal products of labour and imported capital in the sector have fallen as a result of the shock. The development causes movement of oil workers from oil sector to non-oil sector in search of new employment opportunities, job security and better pay, as wage volatility ensues in the economy. Oil capital exhibit high sensitivity to oil price movement. The shock resulted to decline in foreign direct investments and capital accumulation in the oil sector.

Notwithstanding, the non-oil sector appear to benefit from the labour market slack, resulting from the oil sector slump. The non-oil sector's output expands as it attracts more labour resources from the troubled oil sector. Furthermore, non-oil output may have received additional impetus from higher demand for core exports resulting from higher export competitiveness occasioned by the real exchange rate depreciation. The firm does not benefit directly from the oil price decline as its refined oil cost remain unchanged; since refined oil price changes are absorbed[24] wholly by the government. However, the non-oil firm expands its demand for refined

[23]Ninety percent comes from tax on oil firm's net revenue while only ten percent is attributable to lump-sum tax on households

[24]Government receives the differentials (revenue) when oil price falls and pays the differential (cost) when oil price rises.

oil input utilizing savings from the loose [25] labour market. The increased demand for more imported refined oil by domestic firms may exacerbate foreign exchange and inflationary pressures in the economy.

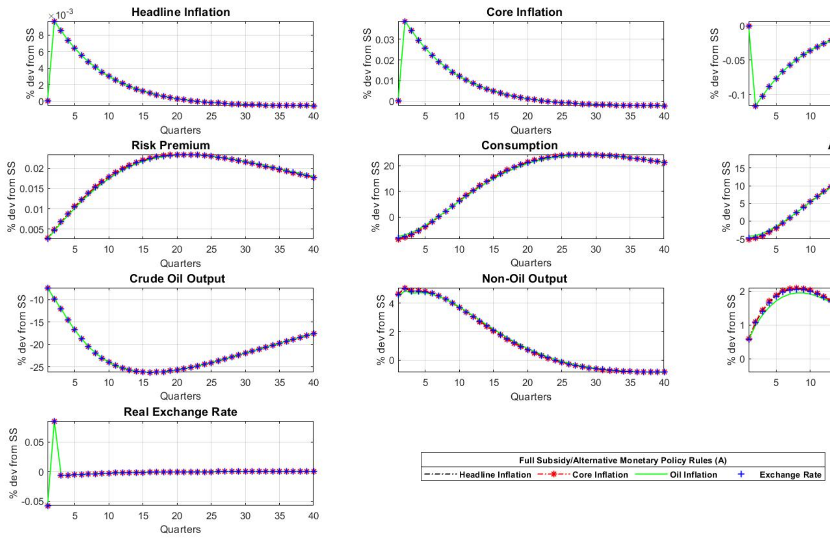

Figure 4.2: Responses to a negative oil price shock given a zero pass-through under alternative monetary policy rules

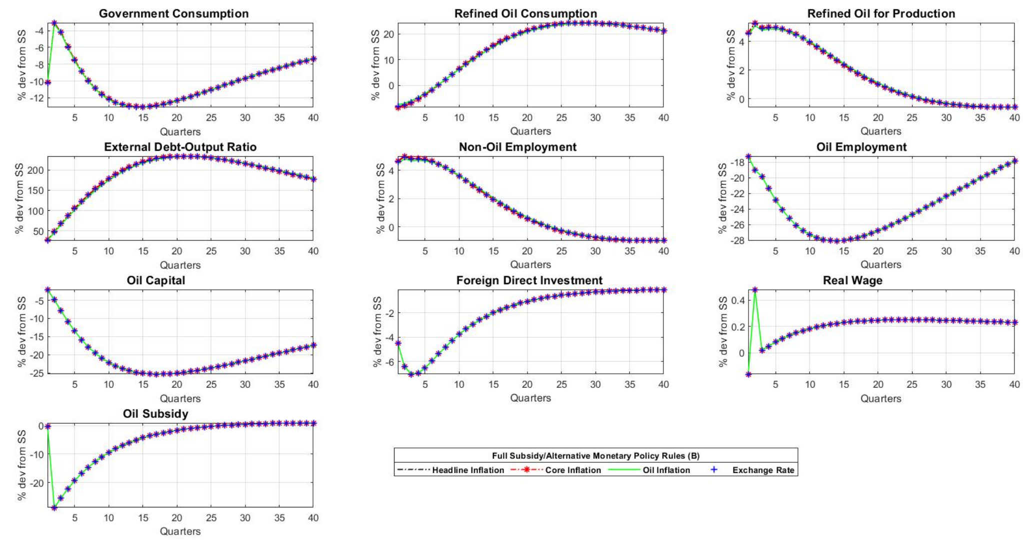

Figure 4.3: Responses to a negative oil price shock given a zero pass-through under alternative monetary policy rules

Under the full subsidy fiscal regime, the negative oil price shock resulted to drop in oil subsidy expenditure by the government after a period lag. This effect is shown

[25] Workers are less expensive to hire.

by the temporary reduction in the size of the fall in government consumption from ten percent on impact to steady state in period two; before plunging further to 14 percent in period fourteen and remained persistent thereafter. This raises a fundamental question on the welfare benefits of oil subsidy on the economy, considering that household oil consumption, household general consumption and government consumption are all negatively impacted by the shock. The reduction in oil subsidy payments does not seem to have any remarkable impact on agents, as both household and government consumption still fell in the aftermath of the oil price shock. The real wage fell on impact before rising in the second period, owing to the increased labour demand from the non-oil sector and exchange rate depreciation.

By raising interest rate, the central bank responds mainly to exchange rate and inflationary pressures. This is not unexpected in a situation where the economy is being simultaneously buffeted by decline in oil and aggregate output and a rise in key inflation measures, resulting from an adverse oil price shock. In such situation, the central bank would be expected to accord priority the price stability, being the primary object of monetary policy. As seen in both figures 4.2 and 4.3, the choice of one monetary policy rule[26] over another does not seem to matter in a fiscal space that inhibits foreign oil price pass-through to the domestic economy. This is because macroeconomic responses to the oil price shock follow similar patterns under all the alternative monetary policy specifications. Our finding underscores how undermining the full price subsidy regime can be for monetary policy transmission mechanism. The absence of foreign oil price pass-through neutralizes almost totally the endogenous differences between alternative monetary policy strategies in our model. Given that refined oil feature in both household consumption basket and domestic firm's production function, it is no surprise that the full subsidy-induced distortion to domestic oil price weighs heavily on monetary policy.

4.4.2 Oil Price shock under alternative monetary policy strategies and partial subsidy regime (partial pass-through)

Under a partial subsidy regime, the government allows only half of the foreign oil price changes to impact the domestic price of imported refined oil. As shown in figures 4.4 and 4.5, the positive response of headline and core inflation to the shock happened on impact and gets bigger in period 2 before decelerating to steady state levels in period 6. The responses are faster and larger under the partial subsidy regime compared to the full subsidy regime, owing to the movement from the zero pass-through under full subsidy to a partial pass-through fiscal intervention. This

[26]These refer to headline inflation targeting, core inflation targeting, oil inflation targeting and exchange rate targeting

shows that the degree of oil price pass-through has affect on inflation's sensitivity to an oil price shock. However, it did not matter which monetary policy framework was operational as both headline and core inflation measures exhibit similar patterns under all monetary policy rules. Notably, oil inflation response was negative on impact and dipped much further by period 2 before turning positive after period 5. Whereas, oil inflation response was mild and negative before returning to steady state under the full subsidy experiment; it showed stronger negative response on impact and in period 2 before turning positive after period 5 under the partial subsidy regime.

The shock elicited instant decline in all consumption variables, arising from the income effect of oil and aggregate output downturn. The variables received stronger impact from a negative oil price shock under the partial subsidy regime, compared to the full subsidy regime. The monetary policy rule with oil inflation target is associated with less sharp oil consumption, aggregate consumption and aggregate output response on impact. The headline, core and exchange rate targeting monetary policy rules are linked to stronger oil consumption, aggregate consumption and aggregate output negative response to the oil shock. Crude oil output decline under a partial subsidy regime is the same with all monetary policy rules.

In response to the shock, non-oil output rose from five percent on impact to nearly twenty percent in the second period. The response derives from the combined effects of the non-oil labour employment increase and the second period real exchange rate depreciation. The two factors improved the non-oil firm's domestic and foreign competitiveness, respectively. It is observed also, that the spike in its demand for more workers in period two may not be unconnected with the rise in foreign demand, buoyed by the second period exchange rate depreciation. Furthermore, the non-oil firm is shown to demand more refined oil input for production under a partial subsidy regime because it enjoys at least half of the benefit the fall in oil factor cost. Similarly, its labour cost too declines given that the oil sector sheds more workers under the partial subsidy regime than under the full subsidy regime. The fall in the real wage, on impact, is far more pronounced under the partial subsidy regime than the full subsidy regime; and so was the period two increase. With less subsidy intervention, the firm's adjustment to labour market dynamics, foreign demand and exchange rate developments appear sharper, as reflected by its demand for more workers, more refined oil and expansion in its output.

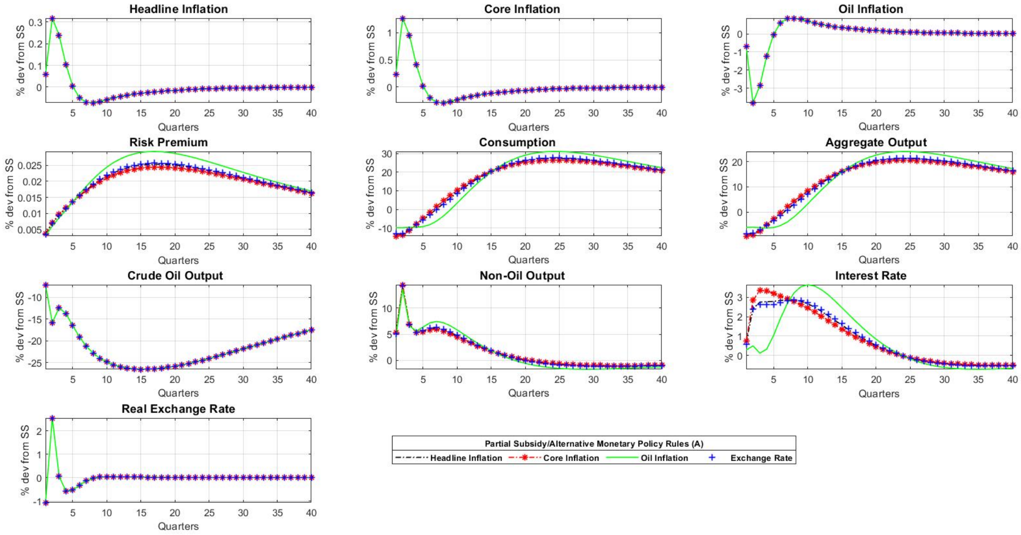

Figure 4.4: Responses to a negative oil price shock given a partial pass-through under alternative monetary policy rules

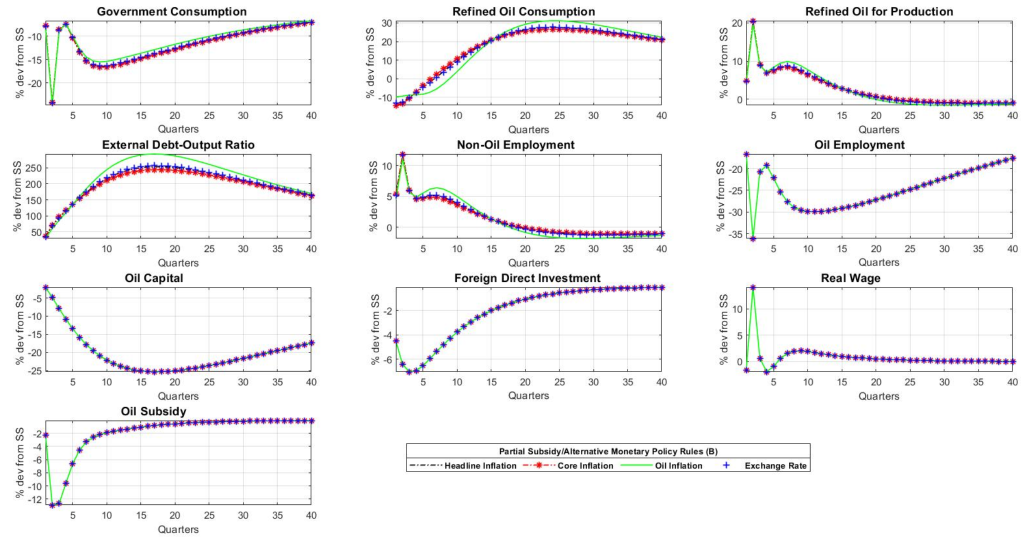

Figure 4.5: Responses to a negative oil price shock given a partial pass-through under alternative monetary policy rules

Given the shock, crude oil output declines, reflecting the loss of oil sector workers and the reversal of oil capital accumulation, owing to a massive decline in foreign direct investments into the oil sector. Whereas, oil capital and foreign direct investment are shown to be indifferent to the degree of pass-through as they maintain similar pattern of responses as under the zero pass-through scenario, oil output and oil employment exhibits stronger negative and volatile responses under the partial pass-through policy. For most variables, the shock elicit similar macroeconomic responses under all monetary policy rules except the oil inflation targeting rule under which many variables exhibit increased volatility. Tracking oil inflation is bound to be problematic given that the underlining variable (i.e. oil price) is volatile and exogenous.

The real exchange rate experiences bigger and longer volatility under a partial subsidy regime, as it appreciates by 1 percent on impact before depreciating by about 2.5 percent in the second period. Exchange rate volatility persists until its final return to steady state in period 8; unlike under the full subsidy regime where exchange rate volatility was contained in size and duration. Households external borrowing condition tightened as risk premium rose in response to the increasing external debt to GDP ratio and dwindling oil revenue. The most profound difference in the impulse responses under the different monetary policy rules is from interest rate response to the shock. Monetary policy response is most aggressive under the core inflation targeting rule and followed by its response under the headline and exchange rate targeting rules. Interest rate response is least aggressive on impact under oil inflation targeting rule but it turns aggressive over time. The initial slow response to the shock under an oil inflation targeting rule may suggest a temporary modest success in anchoring inflation expectations. The result imply that the central bank will switch to a more aggressive monetary policy under the oil inflation rule whenever oil inflation threat become elevated. Such a policy environment will be a very busy one given the volatile nature of oil price.

4.4.3 Oil Price shock under alternative monetary policy strategies and a zero subsidy regime (complete pass-through)

In our zero-subsidy simulation results in figures 4.6 and 4.7, the transmission mechanism of an exogenous oil price shock should be more visible in the domestic economy in the absence of oil price distortions, associated with subsidy. Accordingly, inflation's response to the shock is strongest in the absence of oil subsidy. For headline and core inflation, the impact of the negative oil price shock was immediate, positive and significant up to period 2 before decelerating sharply and returning to steady state in period 15. Similarly, the negative oil inflation response was most significant on impact compared with responses under other subsidy regimes. It moved from about 2 percent fall on impact to about 6 percent in period 2, before recording a minimal positive change in period 5 and finally returned to steady state in period 8. Curiously, however, there are not clear differences between all inflation and exchange rate responses to the shock under alternative monetary policy rules. The situation renders the type of inflation measure or variables targeted in the monetary policy reaction function largely inconsequential for price movement and the real exchange rate. Perhaps, an optimal policy exercise based on optimized simple rules will make the underlining differences between the alternative monetary policy rules less obscure.

Aggregate consumption, oil consumption and aggregate output declined in much the same fashion as under partial subsidy regime; with the response under oil inflation policy rule trailing the rest in terms of response size; and beating the rest in terms of volatility. Government consumption fall was more remarkable under the zero subsidy regime. It fell by 10 percent on impact, dipped further by an additional 25 percent in period 2 and the effect lingered for much longer. The huge decline, though a primary consequence oil tax revenue loss, is compounded by the lack of fiscal opportunity to accrue savings from negative oil subsidy because there is no subsidy under the fiscal regime.

Non-oil firm produce more under the zero subsidy regime than under the full and partial subsidy regimes, although its output is more volatile especially under the oil inflation rule. Core output growth reflects the effects of increased labour employment and higher refined oil utilization in the sector, as well as the increased competitiveness brought about by exchange rate depreciation. The firm benefits from fall in the unregulated price of refined oil, workers lay-offs or movement from the depressed oil sector and the greater demand from abroad. Conversely, output fell on impact by the same margin as under previous fiscal regimes, but it comes with higher volatility under the oil inflation rule and the partial and the zero subsidy regimes. The oil output dip is a direct consequence of negative oil price shock which decreased oil sector's productivity leading to fall in oil sector employment, economy-wide wage volatility, fall in foreign direct investment and oil capital deccumulation.

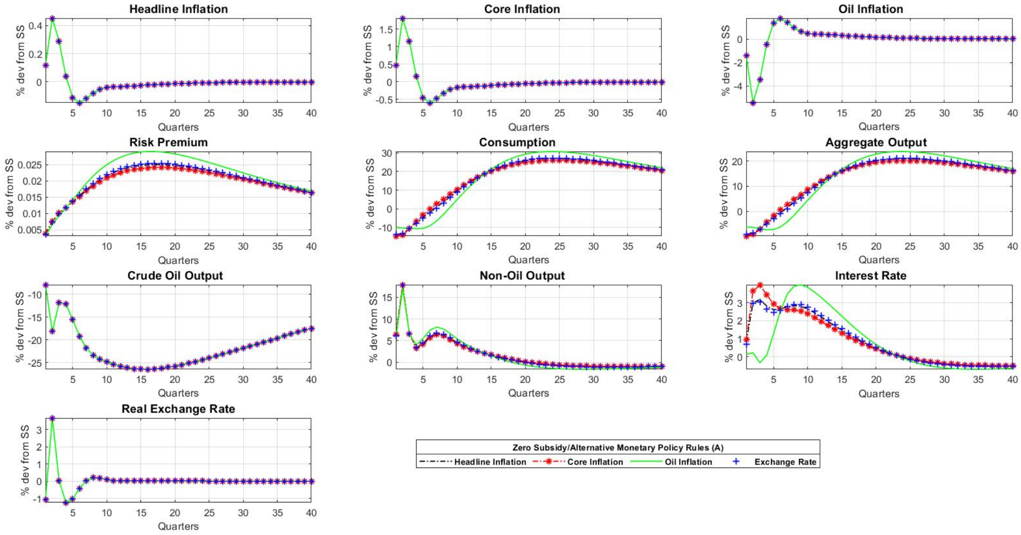

Figure 4.6: Responses to negative oil price shock given a complete pass-through under alternative monetary policy rules

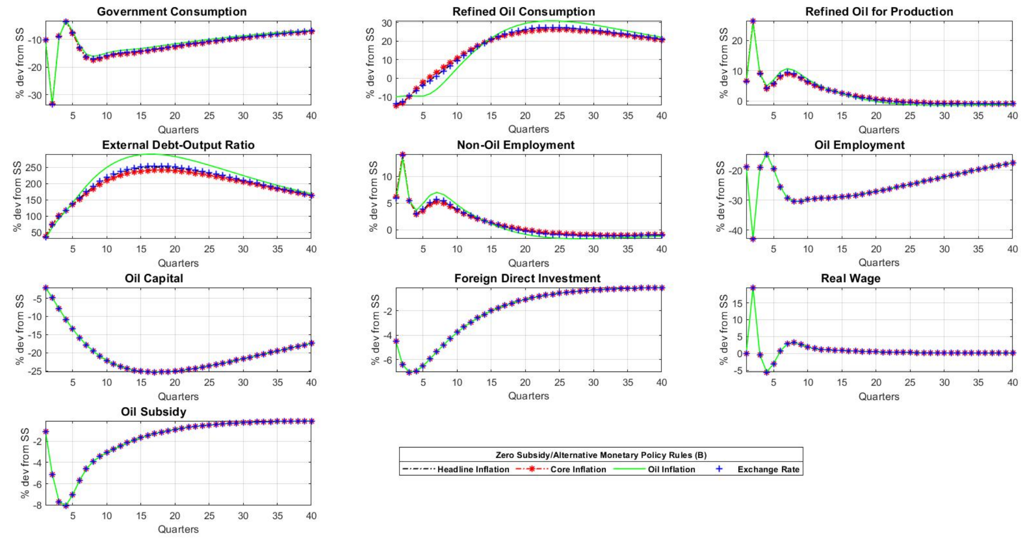

Figure 4.7: Responses to negative oil price shock given a complete pass-through under alternative monetary policy rules

The real exchange rate is most volatile under the zero subsidy market condition, while both risk premium and external debt-to-GDP ratio increased as well. The tightening of external borrowing condition reflects macroeconomic vulnerability due to negative oil price shock, decline in oil earnings, output slump and constrained consumption, among others. The interest rate response to inflationary pressures caused by oil shock is most aggressive under core inflation targeting and least aggressive but most volatile under the oil inflation targeting rule. Given complete foreign oil price pass-through to the domestic economy, the oil inflation targeting rule can not elicit an aggressive interest rate response on impact as the economy experiences decrease in oil inflation. However, the income effect and exchange rate effects of the negative oil price shock, manifesting through output decline and exchange rate depreciation; causes core inflation to rise significantly; prompting an aggressive interest rate response under the core inflation targeting policy rule.

In summary, our results show that the magnitude of macroeconomic responses to the negative oil price shock are comparably smaller under a zero pass-through fiscal policy scenario [27] than under both the partial and full pass-through policies. This result corresponds to Bouakez *et al.* (2008) who reported that under a full subsidy policy, the transmission of a positive oil price shock to the domestic economy is subdued, since subsidy act as a smoother of macroeconomic responses to the shock.

[27] The full subsidy regime

4.5 Optimal Monetary Policy

We implement the optimized simple rules for the four (4) alternative monetary policy rules given the model's equilibrium conditions and a negative crude oil price shock. The experiment is subject to three (3) possible oil subsidy regimes; viz: (i) full subsidy; (ii) partial subsidy; and (iii) zero subsidy. Under each of the fiscal regimes, the coefficients of each of the Taylor-type policy rules are optimized[28] to produce minimum variances associated with an ad-hoc expected loss function. The expression for the variance of the loss function is as follows:

$$E(L_t) = \lambda_\pi Var(\pi_t) + \lambda_y Var(y_t) + \lambda_r Var(i_t) + \lambda_s Var(q_t) \tag{4.127}$$

This represents the weighted average of the unconditional variances of inflation, output, exchange and interest rates. The weights (λ_π, λ_y, λ_q and λ_i) are chosen optimally to achieve the loss function minimization. Policy preferences or weights combination(s) that delivers the minimum loss value post optimization under the alternative monetary policy specifications is deemed to be most welfare superior. In addition, the target instrument under which the minimum loss value is derived will be considered most appropriate for adoption given the state of things in the economy. We follow Alpanda *et al.* (2010), Hove *et al.* (2015) and Ferrero & Seneca (2015) to formulate the relative loss function weights that reveals the policy maker's preferences of 0.5 to 2; resulting in ten (10) alternative plausible weight combinations. Inflation variance weight is normalized to one (1) as it is done in the literature. Each weighted loss function is minimized under each of the alternative simple policy rules to compute the values of central bank losses. Results of the policy exercise are presented in tables 4.3 - 4.6 in the sections that follow.

4.5.1 Optimized Simple Rules with full oil subsidy (zero pass-through)

Allowing for full subsidy or a zero oil price pass-through, optimized simple rules (OSRs) welfare exercise conducted following a negative oil price shock suggests that, either core inflation targeting (CIT) or oil inflation targeting (OIT) will pass for the optimal policy under the policy maker's preference that normalizes inflation to unity and attaches a uniform weight of 0.5 to other variables[29] and the one that maintains the same weight allocations for other variables while assigning 1 to the exchange rate[30]. In terms of the appropriate weighting for each variables in the loss function,

[28] Using Dynare's toolbox for optimized simple rules (OSRs)
[29] This refers to the central bank's preference No. 1.
[30] This refers to the central bank's preference No. 8

optimal policy favours low weights on output and interest rate, while exchange rate weight can be slightly higher or same with inflation weight. However, any exchange rate weight above 1 comes at a significant welfare cost.

CB's Preferences					**Loss values under alternative rules**			
S/N	λ_π	λ_y	λ_i	λ_q	HIT	CIT	OIT	ERT
1	1	0.5	0.5	0.5	1.2135	1.2134	1.2134	1.2843
2	1	1	0.5	0.5	2.291	2.2612	2.2612	2.4652
3	1	1.5	0.5	0.5	3.2973	3.4097	3.2971	3.6349
4	1	2	0.5	0.5	4.3358	4.3283	4.3283	4.8002
5	1	0.5	1	0.5	1.3421	1.3421	1.3421	1.3615
6	1	0.5	1.5	0.5	1.4102	1.4102	1.4102	1.4212
7	1	0.5	2	0.5	1.4632	1.4631	1.4631	1.4712
8	1	0.5	0.5	1	1.2138	1.2134	1.2134	1.2844
9	1	0.5	0.5	1.5	1.2149	1.2135	1.2135	1.2844
10	1	0.5	0.5	2	1.2136	1.2135	1.2135	1.2845

Table 4.3: Loss values under alternative policy rules and zero pass-through

The policy maker's preference that delivers the biggest welfare losses across all monetary policy specifications is the one that assigns maximum weight to output. Any output weight value above the minimum of 0.5 will have adverse welfare consequences. This imply that, given a negative oil price shock realization in a full subsidy environment, it is not optimal for the central bank to be aggressive about minimizing output volatility. Under the circumstance, the worst possible policy choice is to target the real exchange rate in the Taylor rule while trying to minimize output variance in the central bank's loss function in an aggressive fashion[31]. The outcome will be most unfavourable for welfare. Under the zero pass-through scenario, the policy maker may be indifferent in choosing the optimal inflation anchor between core and oil inflation since both yields the same loss value.

4.5.2 Optimized Simple Rules with partial subsidy (partial pass-through)

Assuming a partial subsidy regime in the wake of a negative oil price shock, central bank's preference 1 which assigns the weight of 1 to inflation and 0.5 to other variables is associated with the lowest welfare loss value under oil inflation targeting (OIT) rule. The results, as shown in table 4.4 indicates headline inflation targeting (HIT) trails OIT in terms of welfare performance. Both values are obtained under the same preference combination 1.

[31]Assigning weight of 2 to output variance in the loss function

CB's Preferences					Loss values under alternative rules			
S/N	λ_π	λ_y	λ_i	λ_q	HIT	CIT	OIT	ERT
1	1	0.5	0.5	0.5	1.8711	2.1547	1.861	2.4465
2	1	1	0.5	0.5	3.537	3.4865	3.4788	4.7545
3	1	1.5	0.5	0.5	5.1678	5.1021	5.0959	7.0548
4	1	2	0.5	0.5	6.7957	6.7158	8.8841	9.3524
5	1	0.5	1	0.5	2.0574	2.5274	2.5066	2.5209
6	1	0.5	1.5	0.5	2.2377	2.5274	2.2344	2.5808
7	1	0.5	2	0.5	2.6694	2.6694	2.6694	2.6321
8	1	0.5	0.5	1	1.9323	1.9057	1.9031	2.4974
9	1	0.5	0.5	1.5	1.9478	1.9465	1.9452	2.5307
10	1	0.5	0.5	2	2.0019	1.994	1.9879	2.5728

Table 4.4: Loss values under alternative policy rules and partial pass-through

The preferences with greater emphasis on output stabilization also turn out to be the worst performing in terms of welfare, under all the Taylor rule specifications. Under the partial pass-through scenario, caring too much about output variance[32] under an exchange rate targeting framework will be most welfare-unfriendly. The partial subsidy fiscal policy scenario may be more aligned to reality in most oil rich emerging and frontier small open economies. The common approach is a staggered implementation of subsidy removal, as total oil subsidy removal is often associated with charged social and political tensions in these economies.

4.5.3 Optimized Simple Rules with zero subsidy

In a world with complete oil price pass-through, monetary policy response to a negative oil price shock will be most welfare attractive if the policy maker chooses preference 1, which normalizes the weight on inflation to 1 and assigns 0.5 to the other variables in the loss function and uses oil inflation as the policy anchor[33]. The second best option results from the same policy maker's preference (preference 1) under a core inflation targeting Taylor rule. The worst welfare outcome is attributed to the central bank's preference that places strong weight on output stabilization in the loss function while targeting the real exchange rate in the Taylor rule.

[32]By attaching a high weight (2) to output in the loss function
[33]See table 4.5

CB's Preferences					Loss values under alternative rules			
S/N	λ_π	λ_y	λ_i	λ_q	HIT	CIT	OIT	ERT
1	1	0.5	0.5	0.5	2.3164	2.2954	2.2927	2.8532
2	1	1	0.5	0.5	5.6185	5.5772	5.6387	5.5547
3	1	1.5	0.5	0.5	6.3844	6.2994	6.2788	8.1971
4	1	2	0.5	0.5	11.0186	8.2868	10.8438	10.8397
5	1	0.5	1	0.5	2.4994	2.4973	2.4947	2.9259
6	1	0.5	1.5	0.5	3.0629	3.0629	3.0629	2.9828
7	1	0.5	2	0.5	3.114	3.114	3.114	3.0353
8	1	0.5	0.5	1	2.418	2.384	2.3792	2.9406
9	1	0.5	0.5	1.5	2.4855	3.0595	2.4667	3.028
10	1	0.5	0.5	2	3.1808	2.5597	2.5831	3.1154

Table 4.5: Loss values under alternative policy rules and zero subsidy

CB's Preferences					**Loss values under alternative monetary policy rules and subsidy regimes**											
S/N	λ_π	λ_y	λ_i	λ_q	**Headline Inflation**			**Core Inflation**			**Oil Inflation**			**Exchange Rate**		
					Full	Partial	Zero	Full	Partial	Zero	Full	Partial	Zero	Full	Partial	Zero
1	1	0.5	0.5	0.5	1.2135	1.8711	2.3164	1.2134	2.1547	2.2954	1.2134	1.861	2.2927	1.2843	2.4465	2.8532
2	1	1	0.5	0.5	2.291	3.537	5.6185	2.2612	3.4865	5.5772	2.2612	3.4788	5.6387	2.4652	4.7545	5.5547
3	1	1.5	0.5	0.5	3.2973	5.1678	6.3844	3.4097	5.1021	6.2994	3.2971	5.0959	6.2788	3.6349	7.0548	8.1971
4	1	2	0.5	0.5	4.3358	6.7957	11.0186	4.3283	6.7158	8.2868	4.3283	8.8841	10.8438	4.8002	9.3524	10.8397
5	1	0.5	1	0.5	1.3421	2.0574	2.4994	1.3421	2.5274	2.4973	1.3421	2.5066	2.4947	1.3615	2.5209	2.9259
6	1	0.5	1.5	0.5	1.4102	2.2377	3.0629	1.4102	2.5274	3.0629	1.4102	2.2344	3.0629	1.4212	2.5808	2.9828
7	1	0.5	2	0.5	1.4632	2.6694	3.114	1.4631	2.6694	3.114	1.4631	2.6694	3.114	1.4712	2.6321	3.0353
8	1	0.5	0.5	1	1.2138	1.9323	2.418	1.2134	1.9057	2.384	1.2134	1.9031	2.3792	1.2844	2.4974	2.9406
9	1	0.5	0.5	1.5	1.2149	1.9478	2.4855	1.2135	1.9465	3.0595	1.2135	1.9452	2.4667	1.2844	2.5307	3.028
10	1	0.5	0.5	2	1.2136	2.0019	3.1808	1.2135	1.994	2.5597	1.2135	1.9879	2.5831	1.2845	2.5728	3.1154

Table 4.6: Welfare losses under alternative monetary rules and subsidy regimes

In table 4.6, we present the comparison between the loss values obtained under each Taylor rule specifications and the three subsidy regimes for each specification. The result is shown under ten alternative central bank's loss function weights combinations No. 1 - 10. Evidently, preference 1 returns the least loss values across all monetary policy setup and subsidy regimes. Under this preference, both core and oil inflation targeting maximizes welfare the most in a full subsidy scenario. Although, the model is indifferent between targeting core inflation and oil inflation when oil price pass-through is muted and the first weights combination is selected, the less volatile of the two inflation measures may be preferred.

While a full oil subsidy regime may be popular with the public in oil exporting developing economies, it is the less likely route for fiscal authorities to follow because of fiscal pressures, subsidy administration inefficiencies and the need for oil industry liberalization in order to achieve competitiveness and provide conducive environment for the private sector to flourish. As we demonstrated earlier with impulse responses in 4.2 and 4.3, a full subsidy regime suppresses the intrinsic individual flavour of each alternative monetary policy rules, as they all exhibit the same pattern of response to an oil price shock.

However, assuming a partial or zero subsidy fiscal intervention, targeting oil inflation is shown to be welfare superior to all other monetary policy frameworks in the model. A volatile oil price is very consequential for the household in our model. He consumes oil directly, suffers the burden of higher lump-sum tax resulting from the negative oil price shock and has a limited capacity to smooth consumption due to the borrowing constraint imposed by the risk premium term.

Targeting oil inflation presents a daunting challenge for rule-based interest rate setting strategies, given that oil inflation is hard to track because oil price shock is mainly exogenous and oil price is one of the most volatile commodity prices. Furthermore, a monetary policy framework that actively track oil price developments and responds to oil inflation dynamics may subject the policy maker to the dynamic inconsistency problem which can jeopardize credibility; a commodity it requires to succeed in achieving price stability. In an oil inflation targeting central bank, monetary policy inertia as in Woodford (1999) will become extremely difficult to adhere to. The policy environment will become volatile if interest rate adjustments were to happen in reaction to oil shock-induced inflation dynamics. As shown in figures 4.3 and 4.5, a clear evidence of significant volatility in interest rate response to the negative oil price shock under partial and zero subsidy fiscal conditions is found in our model.

Preference 4 in central bank's loss function weights combinations yield the worst possible welfare results across all Taylor rule specifications and subsidy regimes. This suggest that a net oil exporting small open economy may not achieve optimal policy if it focuses heavily on smoothing output volatility. Output stabilization objective can be more feasible if pursued indirectly through inflation stabilization.

4.6 Conclusion

We build a New Keynesian small open economy DSGE model which capture some structural features of net oil exporting developing and emerging economies. The model highlights crucial structural conditions which make less-developed net oil exporters more susceptible to adverse external events. Using standard small open economy DSGE model parameter values and steady state ratios obtained based on the Nigerian data, we demonstrate through simulation how a negative oil price shock will impact the business cycle under alternative monetary and fiscal policy assumptions.

A negative oil price shock sets off a chain of macroeconomic reactions that saw oil output, aggregate income, government revenue and consumption fall while a reverse Dutch disease situation led to improvement in the non-oil sector output performance. Given a full oil subsidy fiscal regime, monetary policy is shown to be indifferent to alternative target variables as macroeconomic responses to a negative oil price shock are similar under all alternative monetary policy specifications. As subsidy intervention tends toward zero, and pass-through approaches unity, macroeconomic volatility in response to the shock increases. Oil inflation targeting is associated with the least aggressive monetary policy reaction to the shock, but exhibit higher volatility at longer term horizons. Optimal monetary policy exercise reveal that oil inflation targeting has the most welfare gain. This results may have been influenced by our model characterization which captures important stylized facts of a net oil exporter in which refined oil feature as both a consumption good and a production factor. Notably, the argument by Natal (2012) that oil price changes operate as a distortionary tax on disposable income and a source of monetary policy trade-off amplification seems to hold in our model. Given the income effect of a negative oil price shock and the impact of low elasticity of substitution between oil and core goods, stabilizing oil inflation is revealed to be welfare-enhancing.

A monetary policy strategy that targets oil inflation is bound to be fraught with daunting policy challenges. Oil price, the underlining variable for oil inflation, is exogenous and highly volatile and to conduct monetary policy based on its evolution may undermine monetary policy inertia, give rise to dynamic inconsistency problem and erode central bank's credibility, a commodity it requires for monetary policy success. Perhaps, this explains why existing models[34] that feature oil generally abstract from anchoring oil inflation directly when setting up alternative Taylor rules to be optimized. The common practice in the literature is to consider core inflation as the approximate inflation measure to respond to in the event of a persistent oil shock. In our model, the core inflation anchor delivers results nearly equivalent to

[34]See Medina & Soto (2005), Bouakez *et al.* (2008) and Allegret & Benkhodja (2015)

oil inflation anchor, and since the costs of targeting a largely exogenous oil inflation directly cannot be reasonably conceived, the recommended optimal path for practical policy purposes will be to target core inflation. Our proposition aligns with Aissa & Rebei (2012) who recommends that core inflation should be targeted by central banks of economies with regulated prices given that it excludes distortions arising from administered prices.

Monetary policy alone cannot address supply side problems and the structural deficiencies which predispose net oil exporters to external shocks. To that end, net oil exporting emerging and developing countries must improve domestic productivity, ensure proper forward and backward linkages between domestic oil sector and the rest of their economies in order to maximize the benefits of oil endowment, commit to fiscal rules that de-links government fiscal operations from direct oil revenue performance, ensure strong monetary-fiscal policy coordination and re-calibrate their economies to achieve diversification and self-sufficiency in critical sectors.

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